Acta Scientiarum

http://periodicos.uem.br/ojs
ISSN on-line: 1807-8648
Doi: 10.4025/actascihealthsci.v45i1.60517

Tomographic evaluation of changes induced by herbst treatment - buccolingual inclination of mandibular canines and the intercanine distance

João Paulo Schwartz[1,3*], Taisa Boamorte Ravelli[2], Sabine Ruf[3] and Dirceu Barnabé Ravelli[2]

[1]Departamento de Clínica Infantil, Disciplina de Ortodontia, Faculdade de Odontologia de Araraquara, Universidade Estadual Paulista, Rua Humaitá, 1680, 14801-903, Araraquara, São Paulo, Brazil. [2]Departamento de Clínica Infantil, Disciplina de Ortodontia, Faculdade de Odontologia de Araraquara, Universidade Estadual Paulista, Araraquara, São Paulo, Brazil. [3]Department of Orthodontics, Justus-Liebig-Universität Gießen, Giessen, Hessen, Germany. *Author for correspodece E-mail: joaoschwartz@hotmail.com

ABSTRACT. The aim of this study was to perform a three-dimensional evaluation of Herbst appliance effects on the mandibular canines.The subjects consisted of 23 Class II:1 patients (12 men, 11 women), mean age of 15.76± 1.75 years, consecutively 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 canine inclination and mandibular intercanine width at the cusp and apex levels 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. There were no statistical differences between genders. Herbst appliance treatment did not result in any statistically significant changes for mandibular canine inclination and mandibular intercanine width. There were associations between mandibular canine inclination and mandibular intercanine width at the cusp (/r/ = 0.43 to 0.66) and apex levels (/r/ = 0.34 to 0.60). The three-dimensionalcone-beam computed tomography analysis of the mandibular canine segment revealed that the Herbst appliance with a mandibular anchorage unit distant from the incisor's lingual surface does not change mandibular canine inclination and mandibular intercanine width significantly during treatment. However, large interindividual differences may result in undesired amount of mandibular canine anchorage loss in individual patients.

Keywords: Cone-beam computed tomography; orthodontic appliances, functional; cuspid; mandibular advancement; herbst appliance; Angle Class II.

Received on August 11, 2021.
Accepted on February 23 2022.

Introduction

The correct buccolingual inclination of teeth reduces occlusal interferences and promotes adequate intercuspation, anterior and canine guidance as well as the available space for the teeth. As such, it is an important information that influences orthodontic diagnosis and treatment planning, as well as, periodontal health(Andrews, 1972; Yared, Zenobio, & Pacheco, 2006). The mandibular canines are located in an area of special interest adjacent to the mandibular incisors and are of essential functional importance for canine guidance. The mandibular intercanine width depends on mandibular canine inclination and has been shown to be of critical importance for long-term stability of mandibular anterior alignment(Artun, Garol, & Little, 1996).Thus, data on mandibular canine inclination and intercanine width could provide the basis for a better understanding of post-orthodontic treatment changes. Figure 1 shows the change in the position of the mandibular canines immediately after the treatment with Herbst appliance.

The Herbst telescope mechanism is a fixed functional appliance that keeps the mandible in an anterior position and induces skeletal and dentoalveolar changes, as lower incisor proclination and maxillary molar distalization(Pancherz & Ruf, 2008).There are only two studies in the literature that have evaluated mandibular intercanine width changes during the treatment with Herbst appliance with a lingual arch touching the lower incisors.Both did so by using dental casts only. The first study showed a significant increase of mandibular intercanine width from before to after treatment and continuous decrease thereafter until the end of growth(Hansen, Iemamnueisuk, & Pancherz, 1995). The second study reported a decrease of mandibular intercanine width from before to thirty-two-years after treatment with statistical differences from 12 months post-treatment to the end of growth and from 12 months post-treatment to 32 years post-treatment(Pancherz, Bjerklin, Lindskog-Stokland, & Hansen, 2014).To prevent lower incisor proclination a Herbst design with a lower anchorage unit not touching the lingual surface of the lower incisors has been recommended. The effect of this modified anchorage unit on the mandibular canines is yet unknown, either in the short or long-term.

Cone-beam computed tomography (CBCT) allows for an individual, three-dimensional analysis of single teeth and their buccolingual inclination(Shewinvanakitkul, Hans, Narendran, & Martin Palomo, 2011). The use of CBCT has been shown to be useful for the measurement of changes induced by different orthodontic appliances in mandibular intercanine width and mandibular canine inclination(Hamdan, Grunheid, & Larson, 2015; Grunheid, Gaalaas, Hamdan, & Larson, 2016). Up to now, there are no studies in literature analyzing mandibular canine inclination and mandibular intercanine width changes induced by Herbst appliance treatment using CBCT.

The present studyaimed at evaluating, through of CBCT, the changes in mandibular canine inclination and mandibular intercanine width inducedby treatment with a Herbst appliance using a lower anchorage unit not touching the lingual surface of the lower incisors.

Material and methods

This retrospective evaluation of a prospective study, project number 62/10, was approved by the Ethics Committee of Araraquara Dental School, Paulista StateUniversity (FOAr-UNESP). A total of 30 patients meeting the inclusion criteria were invited to participate in the study. However, two patients were excluded because of appliance breakage and five refused to participate. The final sample consisted of 23 consecutively treated (12 male, 11 female; mean age 15.76 ± 1.75 years) patients with Class II division 1 malocclusion. 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. The selection of the sample and the treatment were conducted by two postgraduate students at the department of orthodontics of the Paulista State University (FOAr-UNESP).

Hand wrist radiographs were used to assess the skeletal maturity and estimate the period of the pubertal growth spurt (Hagg & Taranger, 1980). The percentage of cases within the different skeletal maturity groups before treatment were: 4% MP3-G (middle phalanx of the third finger, epiphysis thickened and also cap its metaphysis), 4% MP3-H (middle phalanx of the third finger, fusion of the epiphysis and metaphysis has begun), 17% R-I (distal epiphysis of the radius,fusion of the epiphysis and diaphysis has begun), 27% R-IJ (distal epiphysis of the radius,fusion of the epiphysis and diaphysis is almost completed but there is still a small gap at one or both margins), 48% R-J (distal epiphysis of the radius, fusion of the epiphysis and diaphysis is completed. Completion of facial growth is generally defined by this stage).

The Herbst appliance design used in the present study is shown in 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 plus 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 steel wire) with 3mm distance from the incisor’s lingual surface. 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 changes in mandibular canine inclination and mandibular intercanine width at the cusp and apex levels were evaluate by means of CBCT images 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 13.3 cm of FOV, 120 kV tube voltage, 18.45 mA tube corrent and 0.4 mm isometric voxel size. CBCT images were examined using the Dolphin® Imaging software (Dolphin Imaging & Management Solutions, Chatsworth, CA, USA) by means of multiplanar reconstruction (axial, sagittal and coronal).

Figure 1. Herbst appliance. Maxillary (A) and mandibular (C) anchorage units. Frontal intraoral views after installation (B) and before removal (D) of appliance. Note the changes in mandibular canine inclination.

The metric analysis of the CBCT images was performed as follows. In the first step, the reference plane was 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(Grunheid et al., 2016; Hamdan et al., 2015),(Figure 2). In the coronal and axial view, the cursors are set to intersect the center of the mandibular canine of interest for the assessment of the inclination and in the center of the mandibular left canine for the assessment of the intercanine width. In the sagittal view, the coronal cursor was adjusted in the tooth long axis (cusp tip to root apex), (Grunheid et al., 2016; Hamdan et al., 2015; Shewinvanakitkul et al., 2011), (Figure 3).

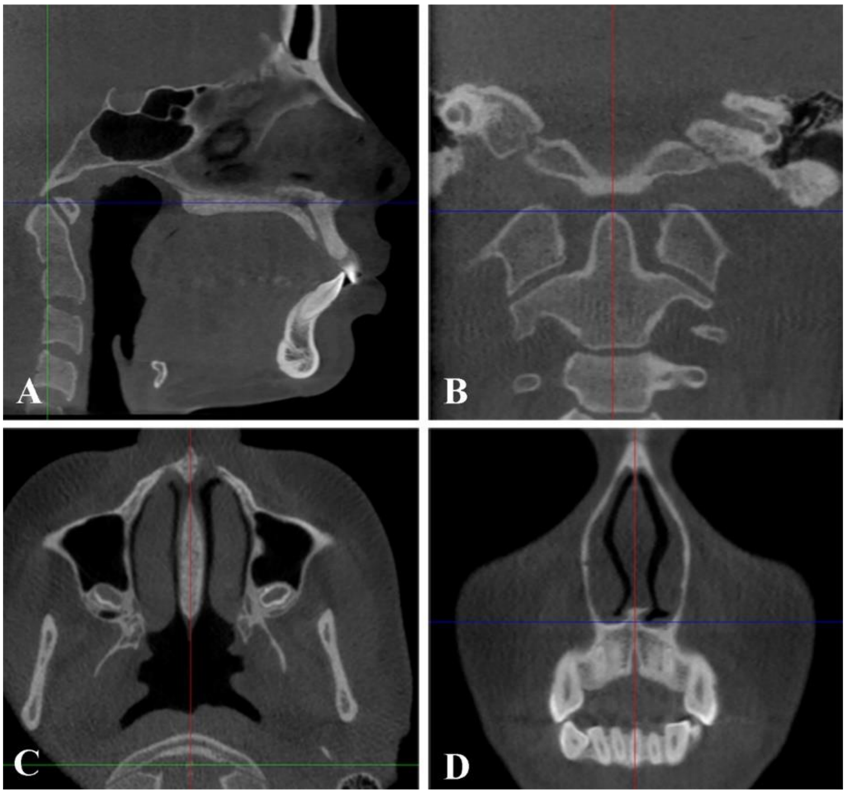


Figure 2. Definition of midsagittal plane as a reference plane for measurements. In the sagittal view, the coronal and axial cursors intersect the superior tip of the odontoid process of the axis and axial cursor, as well, intersect the tip of the anterior nasal spine (A). In the coronal view, the sagittal 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 coronal view, the sagittal cursor intersects the nasion point and the axial cursor intersect the anterior nasal spine (D).

The measurements of mandibular canine inclination and mandibular intercanine width at the cusp and apex levels were performed in coronal multiplanar reconstruction. The mandibular canine inclination was defined as the angle between the long axis of the tooth and the MSP (Figure 3). Positive respectively negative values were given to canines whose crowns were lateral (+) respectively medial (-) to their corresponding roots apices. The measurement of mandibular intercanine width at the cusp and apex levels was linearly between the cusp tips and the roots apex, respectively (Figure 3).

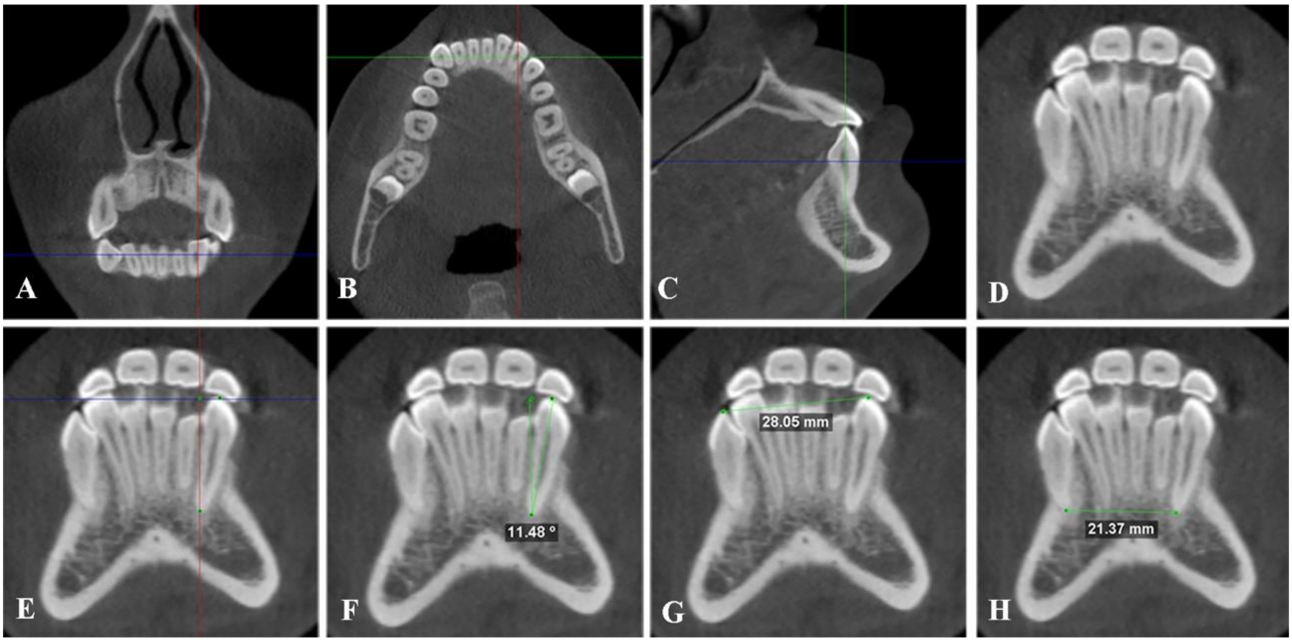


Figure 3. Measurements used to assess and evaluate mandibular canine inclination and mandibular intercanine width at the cusp and apex levels. In the coronal (A) and axial (B) views, the cursors are set to intersect in the center of the mandibular canine of interest. In the sagittal view, the coronal cursor was adjusted in the tooth long axis (C). Coronal multiplanar reconstruction view (D). Reference points for mandibular canine inclination measurement at the cusp tip, at the root apex and at the intersections of the axial and sagittal cursors, positioned at the cusp tip and root apex, respectively (E). Measurements of mandibular canine inclination (F) and mandibular intercanine width at the cusp (G) and apex (H) levels.

All measurements were performed twice by a single calibrated 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 canine inclination (ICC=0.953) and mandibular intercanine width (ICC=0.954). Student's t-Test and Wilcoxont-Test were used to compare dependent samples in parametric and non-parametric cases, respectively, after the data had been tested for normality with the Shapiro-Wilk Test. Student's independent t-Tests was used for gender comparison. Statistical analysis was performed using SPSS® (SPSS Inc, Chicago, IL, USA) and GraphPad Prism® (GraphPad Prism Inc, San Diego, CA, USA). The results were considered at a significance level of 5%.

Results and discussion

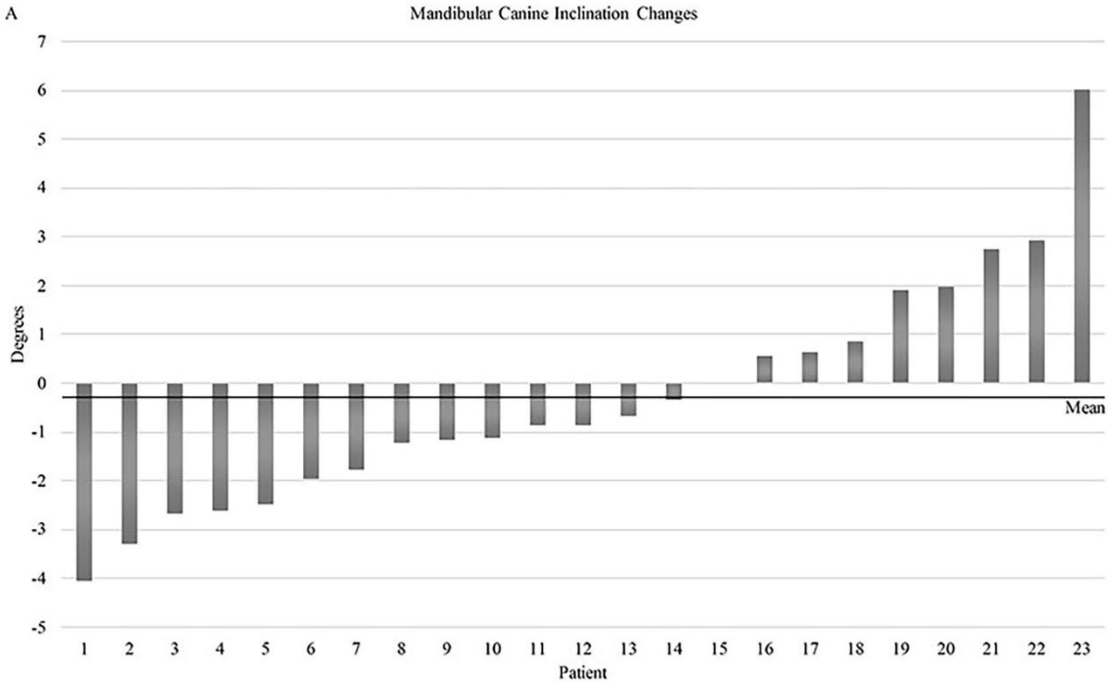
The dentoskeletal pre-treatment characteristics are shown in Table 1. The mean treatment duration with the Herbst appliance was 8.5±0.7 months. Comparisons of mandibular canine inclination and mandibular intercanine width at the cusp and apex levels between genders did not show any statistical differences (Table 2), therefore the data were pooled for further evaluation. The individual mean changes for each patient are shown in Figure 4.

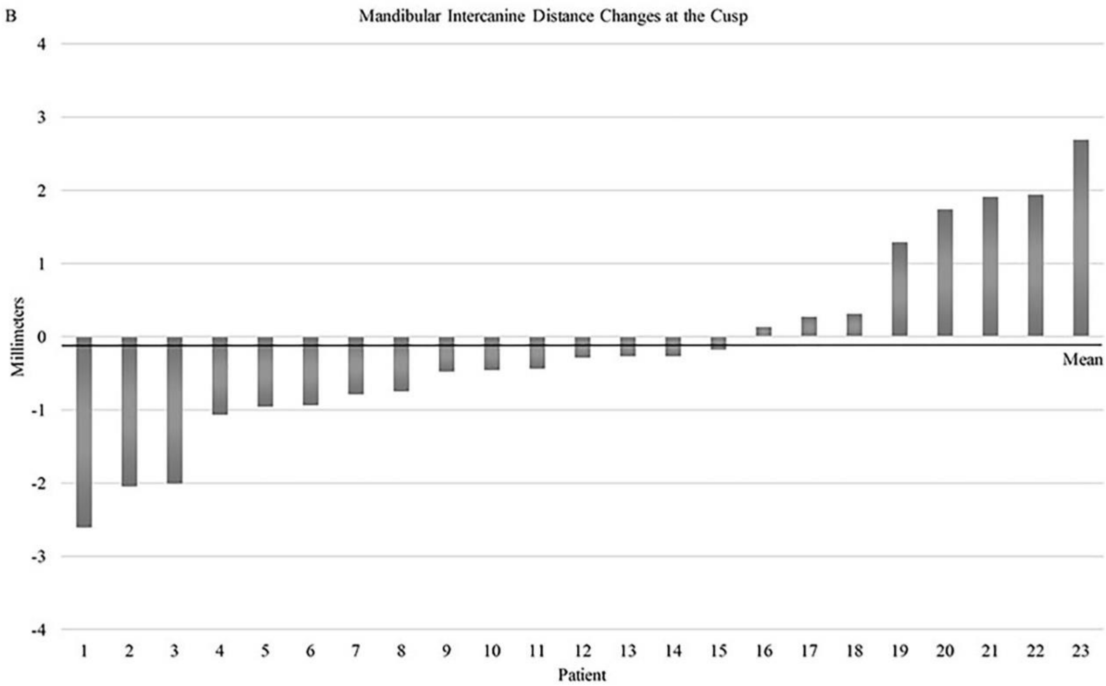
Table 1. Dentoskeletal characteristics of the patients before treatment. Mean ($\bar{x}$) and standard deviation (SD).

Cephalometrics measures	T0, $\bar{x}$ ± SD
SNA, °	81.69 ± 4.11
SNB, °	77.66 ± 3.88
ANB, °	4.34 ± 2.16
WITS, mm	4.49 ± 2.76
IMPA, °	98.39 ± 7.00
1.1, °	116.60 ± 9.99

Table 2. Difference by gender of mandibular canine inclination, mandibular intercanine width at the cusp and apex levels before (T0) and after (T1) treatment. Mean (x̄), standard deviation (SD) and level of significance (P).

Variable	Period	Male	Female	PValue
		x̄± SD	x̄± SD	
Canine Inclination (°)	T0	6.72 ± 4.07	6.76 ± 5.54	0.976
	T1	7.14 ± 4.33	5.62 ± 6.17	0.336
	T1-T0	0.42 ± 0.29	-1.14 ± 0.80	0.079
Cusp Distance (mm)	T0	26.44 ± 2.31	25.14 ± 1.82	0.152
	T1	26.27 ± 1.83	25.02 ± 2.53	0.187
	T1-T0	-0.17 ± 0.12	-0.12 ± 0.08	0.927
Apex Distance (mm)	T0	20.57 ± 2.51	20.85 ± 3.09	0.815
	T1	20.83 ± 2.90	20.53 ± 3.12	0.812
	T1-T0	0.26 ± 0.18	-0.32 ± 0.22	0.512





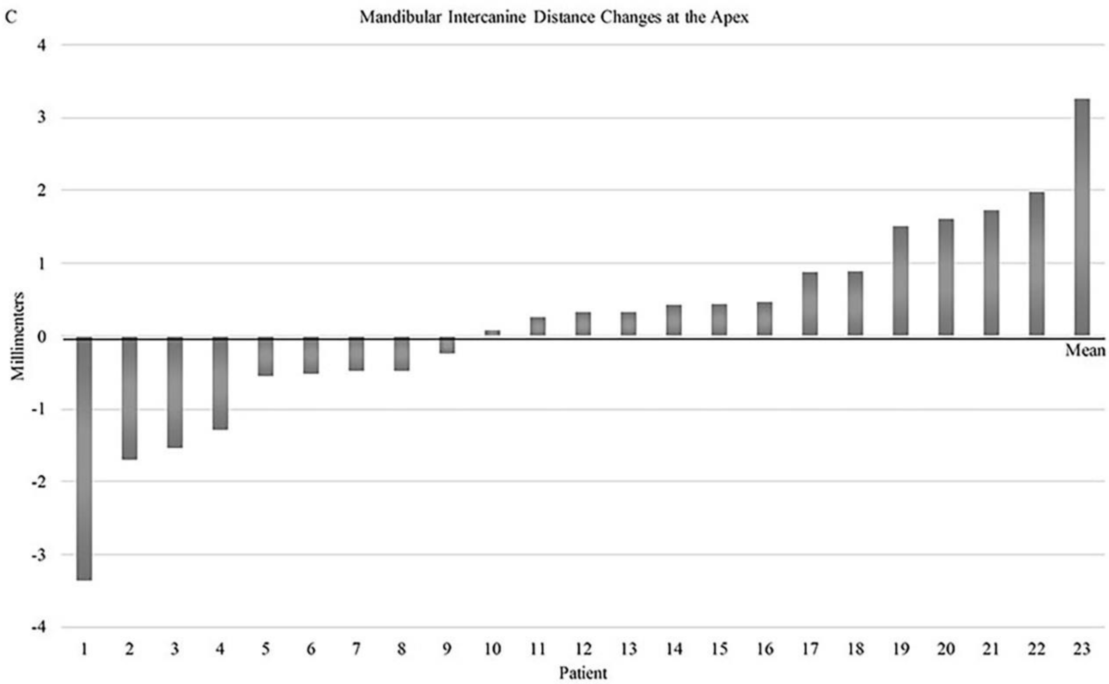


Figure 4. Individual changes (n=23) of average mandibular canines changes (teeth 33 and 43): canine inclination (A), intercanine width at the cusp (B) and apex (C) levels induced by treatment (T1-T0).

The number of cases and percentage of individuals with a positive (=lateral) inclination of the left respectively the right mandibular canine were 23 (100%) and 22 (96%) before treatment and 21 (91%) for both after treatment. Mandibular canine inclination remained unchanged in 1 (4%), increased in 8 (35%) and decreased in 14 (61%) patients, with a wide range of changes (+0.5° to +6.0° and -0.3° to -4.0°). Table 3 shows the means and standard deviations of the changes in mandibular canine inclination. Treatment did not result in any statistically significant changes in mandibular canine inclination, although there were large unforeseeable individual differences (Figure 4).

Table 3. Mean (x̄), standard deviation (SD) and level of significance (P) of mandibular canine inclination before (T0) and after (T1) treatment.

Inclination (°)	n	T0	T1	T1-T0	PValue
		x̄± SD	x̄± SD	x̄± SD	
33	23	6.42 ± 4.04	5.70 ± 4.70	-0.72 ± 0.50	0.265
43	23	7.05 ± 5.48	7.13 ± 5.82	0.08 ± 0.05	0.855
Total	46	6.74 ± 4.77	6.41 ± 5.28	-0.33 ± 0.23	0.470
Male	24	6.72 ± 4.07	7.14 ± 4.33	0.42 ± 0.29	0.505
Female	22	6.76 ± 5.54	5.62 ± 6.17	-1.14 ± 0.80	0.070

Mandibular intercanine width at the cusp level increased in 8 (35%) and decreased in 15 (65%) patients, with a wide range of changes (+0.1 to +2.7 mm and -0.2 to -2.6 mm). Mandibular intercanine width at the apex level increased in 14 (61%) and decreased in 9 (39%) patients, with a wide range of changes (+0.1to +3.2mm and -0.2to -3.3mm). Table 4 show the means and standard deviations of the changes in mandibular intercanine width at the cusp and apex levels. Treatment did not result in any statistical differences, however, there were large individual differences with increases and decreases (Figure 4).

This CBCT study evaluated the three-dimensional changes in mandibular canine inclination and mandibular intercanine width at the cusp and apex levels induced by Herbst appliance treatment. This is the first study to evaluate mandibular canine inclination and mandibular intercanine width at the apex level after Herbst treatment and there are no comparable studies in literature.

The mean age of the patients were 15.76 years and the skeletal maturity evaluation showed that more than 90% of the sample was in the post-pubertal period, a developmental stage during which a Class II treatment with the Herbst appliance shows more dentoalveolar than skeletal changes (Ruf & Pancherz, 2003).

Table 4. Mean ($\bar{x}$), standard deviation (SD) and level of significance (P) of mandibular intercanine width at the cusp and apex levels before (T0) and after (T1) treatment.

Distance (mm)	Variable	n	T0	T1	T1-T0	PValue
			$\bar{x}$± SD	$\bar{x}$± SD	$\bar{x}$± SD	
Cusp	Total	46	25.81 ± 2.15	25.67 ± 2.23	-0.14 ± 0.09	0.617
	Male	24	26.44 ± 2.31	26.27 ± 1.83	-0.17 ± 0.12	0.713
	Female	22	25.14 ± 1.82	25.02 ± 2.53	-0.12 ± 0.08	0.752
Apex	Total	46	20.71 ± 2.73	20.69 ± 2.94	-0.02 ± 0.01	0.986
	Male	24	20.57 ± 2.51	20.83 ± 2.90	0.26 ± 0.18	0.571
	Female	22	20.85 ± 3.09	20.53 ± 3.12	-0.32 ± 0.22	0.685

Regarding the acquisition of tomographic images, the accuracy of CBCT for linear measurements has been reported not to differ significantly between different voxel resolutions (0.2 and 0.4mm), (Patcas, Muller, Ullrich, & Peltomaki, 2012; Ponder, Benavides, Kapila, & Hatch, 2013). Furthermore, the three-dimensional CBCT images allow an assessment of the buccolingual inclination of individual teeth with good accuracy in any given plane (Gribel, Gribel, Frazao, McNamara, & Manzi, 2011; Shewinvanakitkul et al., 2011). The CBCT images used in the present study were originally obtained for a prospective study and, after the treatment with the Herbst appliance, the authors observed clinically canine anchorage loss induced by the anchorage unit not touching the lingual surface of the lower incisors. Therefore, this retrospective evaluation was conducted with the same sample of the prospective study taking into account that combining mandibular canine inclination and mandibular intercanine width data provide better insight into the three-dimensional positional changes of the mandibular canines (Grunheid et al., 2016). Despite of the possible indications for CBCT use, the radiation doses should be kept as low as reasonably achievable, according the ALARA principle.

There were no statistical differences between genders in mandibular canine inclination and mandibular intercanine width at the cusp and apex neither before nor after treatment. Only one study also evaluated gender differences by means of dental cast (Hansen et al., 1995). In concordance with the present findings, no gender differences for mandibular intercanine width at the cusp level was found, neither for the active treatment period nor for during the post-treatment period until the end of growth.

The mandibular intercanine width at the cusp level determined in our study at T0 (25.8mm) and T1 (25.7mm) are in accordance with average mandibular intercanine width of 24 to 26 mm reported in literature (Moorrees, Gron, Lebret, Yen, & Frohlich, 1969; Bishara, Jakobsen, Treder, & Nowak, 1997). Neither mandibular canine inclination nor mandibular intercanine width at the cusp and apex levels changed significantly during Herbst treatment. The average inclination changes of both canines amounted to -0.33°, thus indicating a lingual inclination. Correspondingly, on average the intercanine width at the cusp also decreased (-0.14 mm). Thus, the present results range between the findings in literature that showed a decrease in intercanine width at the cusp of -0.6 mm(Pancherz et al., 2014) during treatment and the results that indicated an increase in intercanine width of +0.3 et al., 1995). Given small absolute dimension of changes the different design of the anchorage unit (lingual arch touching/not touching the lower incisors), does not seem to result in clinically relevant differences at the mandibular canine segment. However, in concordance with the literature (Hansen et al., 1995) and for unknown reasons there were large interindividual differences showing both substantial decreases and substantial increases, thus possibly resulting in clinically relevant changes for individual patients (Figure 5). The canine anchorage loss was most likely induced by the anchorage unit used in the present study in which the labial cantilever exerts a downward and forward directed force and a clockwise movement on the mandibular anchorage unit. The contact of the anchorage unit with the distal surface of the canine will favor the reported canine anchorage loss.

One fact that must be taken in count in our investigation is that the changes induced by the treatment were evaluated immediately after the Herbst appliance treatment phase. Furthermore, given the canine anchorage loss and decrease in mandibular intercanine width at the cusp level in 65% of the patients, the multibracket appliance treatment phase following the Herbst phase analyzed in the present paper will most likely result in secondary incisor proclination (Martin & Pancherz, 2009; Bremen, Ludwig, & Ruf, 2015; Elkordy, Aboelnaga, Fayed, AboulFotouh, & Abouelezz, 2016; Bock, Killat, & Ruf, 2021; Iyer, Premkumar, & Muruganandam, 2021; Karbach, Zoller, Zoller, Wehrbein, & Erbe, 2021).

As already mentioned, this retrospective evaluation was conducted with the same sample of a prospective study. The authors realized clinically that immediately after the treatment with the Herbst appliance the canines changed his position because the type of the anchorage used in this study (Figure 1). The results shows that there is no change in the intercanine width or inclination of mandibular canines. According with the Figure 5, probably the mandibular canines move to mesial and induce a crowding in the lower incisor/canine area. In the modern Herbst therapy, after the orthopedic phase starts the multibracket appliance phase and the crowding may result in secondary incisor proclination.

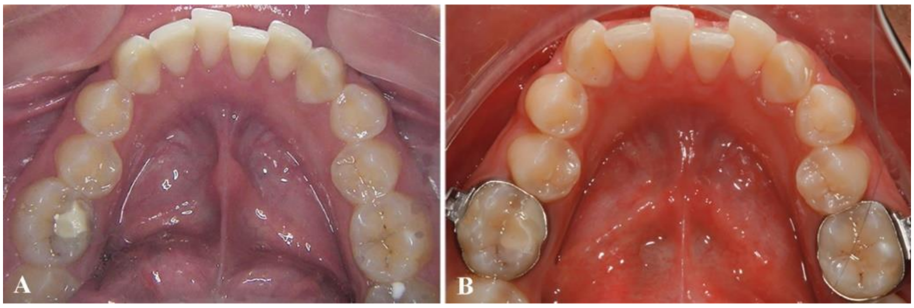


Figure 5. Mandibular dental arch before (A) and after (B) Herbst appliance treatment. Note the canine anchorage loss.

The limitations that should be considered when interpreting the results of the present study 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 should be considered in future research project. Especially future studies analyzing the total orthodontic treatment period (Herbst plus Multibrackets appliance) are needed.

Conclusion

The three-dimensional CBCT analysis of the mandibular canine segment revealed that the Herbst appliance with a mandibular anchorage unit distant from the incisor's lingual surface does not change mandibular canine inclination and mandibular intercanine width significantly during treatment. However, large interindividual differences may result in undesired amount of mandibular canine anchorage loss in individual patients.

Acknowledgements

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) Brazil - Finance Code 001, Programa Doutorado Sanduíche no Exterior (PDSE-CAPES) process number 88881.133389/2016-01.

References

Andrews, L. F. (1972). The six keys to normal occlusion. *American Journalof Orthodontics*, *62*(3), 296-309. DOI: https://doi.org/10.1016/s0002-9416(72)90268-0

Artun, J., Garol, J. D., & Little, R. M. (1996). Long-term stability of mandibular incisors following successful treatment of Class II, Division 1, malocclusions. *The Angle Orthodontist, 66*(3), 229-238. DOI: https://doi.org/10.1043/0003-3219(1996)066<0229:LTSOMI>2.3.CO;2

Bishara, S. E., Jakobsen, J. R., Treder, J., & Nowak, A. (1997). Arch width changes from 6 weeks to 45 years of age. *American Journal of Orthodontics and Dentofacial Orthopedics*, *111*(4), 401-409. DOI: https://doi.org/10.1016/s0889-5406(97)80022-4

Bock, N. C., Killat, S., & Ruf, S. (2021). Efficiency and outcome quality of Herbst-Multibracket appliance therapy in Class II:2 patients. *European Journal of Orthodontics*, *44*(2), 117-124. DOI: https://doi.org/10.1093/ejo/cjab021

Bremen, J., Ludwig, B., & Ruf, S. (2015). Anchorage loss due to Herbst mechanics-preventable through miniscrews? *European Journal of Orthodontics*, *37*(5), 462-466. DOI: https://doi.org/10.1093/ejo/cju058

Elkordy, S. A., Aboelnaga, A. A., Fayed, M. M., AboulFotouh, M. H., & Abouelezz, A. M. (2016). Can the use of skeletal anchors in conjunction with fixed functional appliances promote skeletal changes? A systematic review and meta-analysis. *European Journal of Orthodontics*, *38*(5), 532-545. DOI: https://doi.org/10.1093/ejo/cjv081

Gribel, B. F., Gribel, M. N., Frazao, D. C., McNamara, J. A., Jr., & Manzi, F. R. (2011). Accuracy and reliability of craniometric measurements on lateral cephalometry and 3D measurements on CBCT scans. *The Angle Orthodontist*, *81*, 26-35. DOI: https://doi.org/10.2319/032210-166.1

Grunheid, T., Gaalaas, S., Hamdan, H., & Larson, B. E. (2016). Effect of clear aligner therapy on the buccolingual inclination of mandibular canines and the intercanine distance. *The Angle Orthodontist*, *86*, 10-16. DOI: https://doi.org/10.2319/012615-59.1

Hagg, U., & Taranger, J. (1980). Skeletal stages of the hand and wrist as indicators of the pubertal growth spurt. *Acta Odontologica Scandinavica*, *38*(3), 187-200. DOI: https://doi.org/10.3109/00016358009004719

Hamdan, H. A., Grunheid, T., & Larson, B. E. (2015). Effect of orthodontic treatment with preadjusted edgewise appliances on the buccolingual inclination of mandibular canines: a CBCT study. *Orthodontics & Craniofacial Research*, *18*(3), 156-164. DOI: https://doi.org/10.1111/ocr.12092

Hansen, K., Iemamnueisuk, P., & Pancherz, H. (1995). Long-term effects of the Herbst appliance on the dental arches and arch relationships: a biometric study. *Britsh Journal of Orthodontics*, *22*(2), 123-134. DOI: https://doi.org/10.1179/bjo.22.2.123

Iyer, S. R., Premkumar, S., & Muruganandam, M. (2021). Skeletal and dental changes induced by the Flip-Lock Herbst appliance in the treatment of Angle's class II division 1 malocclusion during active growth period: A preliminary study. *Journal of Dental Research, Dental Clinics*, *Dental Prospects*, *15*, 59-65. DOI: https://doi.org/10.34172/joddd.2021.011

Karbach, M., Zoller, C., Zoller, G., Wehrbein, H., & Erbe, C. (2021). The Herbst appliance and its modifications - prevalence and individuality. *Head and Face Medicine*, *17*, 15. DOI: https://doi.org/10.1186/s13005-021-00266-2

Martin, J., & Pancherz, H. (2009). Mandibular incisor position changes in relation to amount of bite jumping during Herbst/multibracket appliance treatment: a radiographic-cephalometric study. *American Journal of Orthodontics and Dentofacial Orthopedics*, *136*, 44-51. DOI: https://doi.org/10.1016/j.ajodo.2007.07.027

Moorrees, C. F., Gron, A. M., Lebret, L. M., Yen, P. K., & Frohlich, F. J. (1969). Growth studies of the dentition: a review. *American Journal of Orthodontics*, *55*(6), 600-616. DOI: https://doi.org/10.1016/0002-9416(69)90037-2

Pancherz, H., Bjerklin, K., Lindskog-Stokland, B., & Hansen, K. (2014). Thirty-two-year follow-up study of Herbst therapy: a biometric dental cast analysis. *American Journal of Orthodontics and Dentofacial Orthopedics*, *145*(1), 15-27. DOI: https://doi.org/10.1016/j.ajodo.2013.09.012

Pancherz, H., & Ruf, S. (2008). *The Herbst appliance. Research-based clinical management*. London, UK: Quintessence Publishing Co Ltd.

Patcas, R., Muller, L., Ullrich, O., & Peltomaki, T. (2012). Accuracy of cone-beam computed tomography at different resolutions assessed on the bony covering of the mandibular anterior teeth. *American Journal of Orthodontics and Dentofacial Orthopedics*, *141*, 41-50. DOI: https://doi.org/10.1016/j.ajodo.2011.06.034

Ponder, S. N., Benavides, E., Kapila, S., & Hatch, N. E. (2013). Quantification of external root resorption by low- vs high-resolution cone-beam computed tomography and periapical radiography: A volumetric and linear analysis. *American Journal of Orthodontics and Dentofacial Orthopedics*, *143*, 77-91. DOI: https://doi.org/10.1016/j.ajodo.2012.08.023

Ruf, S., & Pancherz, H. (2003). When is the ideal period for Herbst therapy - early or late? *Seminars in Orthodontics*,*9*, 47-56.DOI: https://doi.org/10.1053/sodo.2003.34024

Shewinvanakitkul, W., Hans, M. G., Narendran, S., & Martin Palomo, J. (2011). Measuring buccolingual inclination of mandibular canines and first molars using CBCT. *Orthodontics & Craniofacial Research*, *14*(3), 168-174. DOI: https://doi.org/10.1111/j.1601-6343.2011.01518.x

Yared, K. F., Zenobio, E. G., & Pacheco, W. (2006). Periodontal status of mandibular central incisors after orthodontic proclination in adults. *American Journal of Orthodontics and Dentofacial Orthopedics*, *130*(1), 6e1-8. DOI: https://doi.org/10.1016/j.ajodo.2006.01.015