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Comparison of cross-sectional orthodontic analysis on digital models using Nemocast and CBCT software

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Abstract
Model measurements and analysis are essential for the diagnosis of orthodontic cases and in the last decade orthodontic diagnosis has increased with technological advances, leaving aside traditional diagnostic methods, such as model analysis, especially when it comes to cross-sectional analysis. The present study seeks to propose to the clinician a simple option in the diagnosis of the transversal problem, through analysis with the CBCT. To support this proposal, data was collected from 40 students who were evaluated according to the parameters established in the study, between the ages of 21 and 27. Data were taken from digital study models in STL format, as well as CBCT. The UPenn analysis was used in the CBCT and applying the Korkhaus and Wala Ridge analyzes for the STL digital models, establishing comparisons of the validity of the results by calculating the predictive values of the positive test and the negative test. Model analysis was performed by measuring, using the NemoCast3D software. The comparison of means of both measures was carried out, which showed that there is no significant difference and then the correlation of measures was made, which proved to be significant in 5 of 7 measures. This model analysis proposal (AN-BAR) can be useful for the clinician in making a decision when performing a maxillary expansion.

Keywords: Digital models; Cone beam computed tomography; Transverse discrepancy; Korkhaus analysis; Wala Ridge analysis; Penn analysis

1. Introduction
The diagnosis in orthodontics should be made in a global way, both in dental structures and bone structures, with a correct diagnosis can be made proper planning and implementation of orthodontic treatments that will be preventive, interceptive and corrective. These diagnostic records provide information about the conditions of the patient at the time of starting treatment. Among these are the study models, which provide information about the shape of the arches, their symmetry, the amount of crowding, number and size of the teeth, presence or absence of diastemas and rotations. It is also possible to take measurements to determine the amount of space required for all teeth to be aligned correctly [1].

The objectives of the orthodontic specialist are clearly established, its purpose is to achieve a functional, harmonious and stable occlusal relationship, by correcting the problems in the three directions of space, all this starts from a correct diagnosis; for this purpose, and several methods are available to diagnose the relationships between the jaws in the vertical, transverse and sagittal dimensions [2].

Nowadays the most widely used method for transverse diagnosis is the tomographic analysis (CBCT) proposed by the University of Pennsylvania-2010 (UPenn Analysis) because with the advent of 3D, accurate measurements can be obtained without major distortion of structures, with greater ease in the localization of anatomical points. This

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diagnostic approach consists of determining the amount of transverse discrepancy between the jaws and is based on the easily discernible use of landmarks [2].

1.1. Orthodontics

Orthodontics is the area of dentistry that relates to facial growth, dentition development and occlusion, along with prevention and correction of occlusal abnormalities, finding that the main indications for orthodontic treatment are to improve oral function, esthetics and overall dental health [3].

1.2. Orthodontic diagnosis

To establish a diagnosis in orthodontics it is important to know the clinical history in an exhaustive way and many times the analysis begins from the moment the patient enters the office. An important aspect is to know the stage of development in which the patient is in order to choose the best approach to orthodontic treatment, knowing details such as height, weight, sexual characteristics allows us to determine the amount of development.

Diagnosis in orthodontics should be performed in the three planes of space to achieve coordination and harmony of arches at the end of treatment [3].

The sagittal and vertical planes are often overemphasized and the transverse plane is neglected.

1.3. Cross-cutting dimension

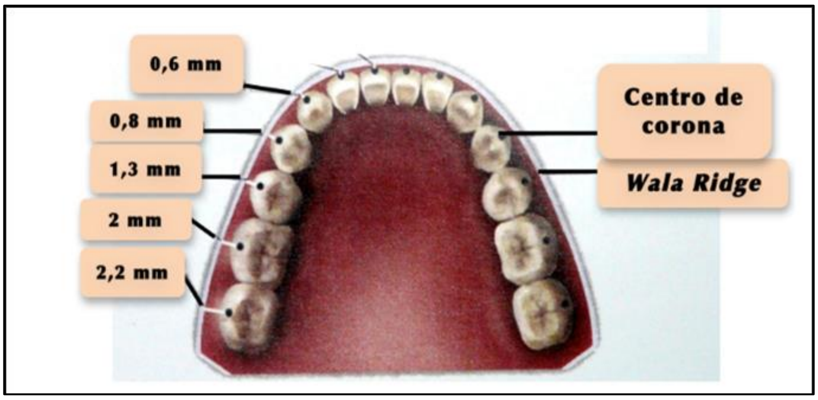
It is evaluated by considering lower anterior face height and mandibular plane inclination, because short anterior facial height can be associated with deep overbites and long anterior face heights with open bites, conditions that are difficult to correct with orthodontics alone, with lower jaw border inclination or mandibular plane angle resulting from rotation of the mandible during growth. Therefore, if the rotation is greater or less than average, it gives rise to unbalanced vertical facial proportions, the greater the skeletal difference, the more likely the patient will need a combination of orthodontics and orthognathic surgery to correct the occlusion and the underlying skeletal discrepancy, plus the contribution of skeletal growth to the malocclusion makes treatment more difficult and complex [4].

Diagnosis of the transverse plane can be made by posteroanterior radiography, Cone-Beam tomography or study models [3].

McNamara places great value on the measurement of intermolar width, measured at the intersection of the palatal sulcus with the gingival margin, as an indicator of the development of the maxillary bone base. Under normal conditions the intermolar width in the mixed dentition is 34-35 mm and in the adult permanent dentition it is 36 to 39 mm [5].

1.4. Analysis of Wala Ridge

The Wala Ridge line is defined as the junction between the basal bone and the alveolar bone. It corresponds clinically to the mucogingival line. The Wala analysis has been taken as a diagnostic reference to determine the amount of expansion to be achieved at the end of orthodontic treatment [6].



Source: Taken from Napa [13].

Figure 1 Ideal measurements of Wala Ridge analysis established by Andrews

The Wala analysis has been taken as a diagnostic reference to determine the amount of expansion to be achieved at the end of orthodontic treatment [6].

This analysis compares the distances between the centers of the clinical crowns of the teeth with the distance between the projections of these points on the mucogingival line. The aim of this method is to predict the transverse position that the posterior teeth will have when they harmonize with their basal bone. The values reported by Andrews [7] are taken as a reference.

The WALA border is a simple anatomical structure to locate clinically, being observed as a whitish pink line in the area of the mucogingival junction. This anatomical structure is also located in plaster models, as the most convex part of the vestibular face where the bony structure would be located [4].

To begin with, only the posterior segment of the arch from the canine to the second molar should be taken into account.

The width of the jaw must be determined.

1.5. Korkhaus analysis

The Korkhaus analysis is based on the results of the study on palatal depth measurements, finding a relationship between the width of the posterior arch and the palatal depth in cases with normal occlusion, considering this type of analysis the anteroposterior length of the arch represented by the distance between the contact points of the upper central incisors and a point located in the center of the maxillary fissure at the level of the premolars and molars, using an orthometer for the application [7].

The advantages of the Pont index lie in the ease of application and the valuable information it could provide to aid treatment planning. However, the use of this index remains highly controversial with some investigators supporting its use to predict arch widths (Stifter, Gupta et al,), and others believing that the Pont Index is unreliable and should not be used for clinical purposes [8].

1.6. Penn analysis

With the advent and evolution of cone beam imaging, orthodontists can obtain accurate measurements without any distortion caused by radiographic projections or ambiguity in point identification. The same reasoning can subsequently be applied to transverse measurement of the maxilla and mandible [2].

The Penn analysis; taking as reference points for the maxillary width, the Yugal-Yugal cephalometric points of Ricketts, and for the mandibular width the WALA Ridge. In the CBCT images, in axial and coronal slices, the J-J points are taken to measure the maxillary width; then, the mandibular width is measured at the level of the intersection of the cortical bone of the lower first molars. By subtracting the maxillary width from the mandibular width, the difference between the two is determined. An example is shown in Penn's transverse discrepancy analysis; which demonstrates a transverse collapse of the maxilla of 3.6mm; 5mm being the norm [9

The objective of the present study is to establish the cross-sectional discrepancy and compare the same between the analyses of digital models in STL format with the analysis of Computed Cone-Beam Tomography.

2. Material and method

An analytical and retrospective study was carried out on study models of undergraduate students at the Faculty of Dentistry of the University of Cuenca in the year 2022-2023. The registration of the study models was obtained with prior approval of the selected students. The study universe was constituted by 40 students taking the chair of Orthodontics of the Undergraduate area of the Faculty of Dentistry of the University of Cuenca in the period September 2022- February 2023 with ages between 21 and 27 years, collecting the digital models using Nemocast and CBCT software, following the methodological design of the study by Guerra et al. (2018) [3], dividing the sample as follows:

- 10 male patients.
- 20 female patients.

A sample of 30 patients was obtained that met the inclusion criteria, such as: models with complete permanent dentition and its digital counterpart, correctly preserved models with intact canines and first permanent molars. Physical models that present giroversions of canines or molars, severe crowding were excluded (Table 1). Digital models that present file defect in the software, with changes or modifications caused by previous manipulations were excluded.

In order to perform the Korkhaus index and Wala Ridge analysis of the upper and lower models, values expressed in millimeters, were performed through NemoCast 3D and CBCT considering the study variables (Table 2).

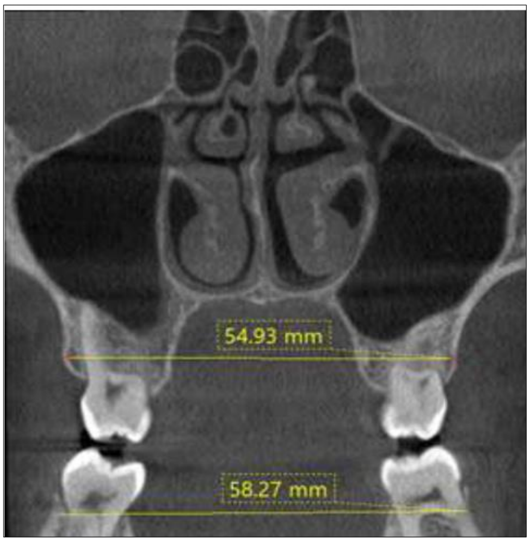
Table 1 Inclusion and exclusion criteria

Inclusion Criteria	**Exclusion Criteria**
Models showing complete permanent dentition and their digital counterpart	Digital models showing gyroversions of canines or molars
Properly preserved models with intact permanent canines and first permanent molars.	Digital models presenting severe crowding
	Digital models that present a file defect in the software, with changes or modifications caused by previous manipulations.

Source: author

2.1.1. Standardization and analysis of digital models and CBCTs

Prior to the analysis, the standardization of the researchers was performed, which was the same throughout the study, consisting of the application of the Korkhaus and Wala Ridge analyses for digital models and the Penn analysis for computed tomography.



Source: Author

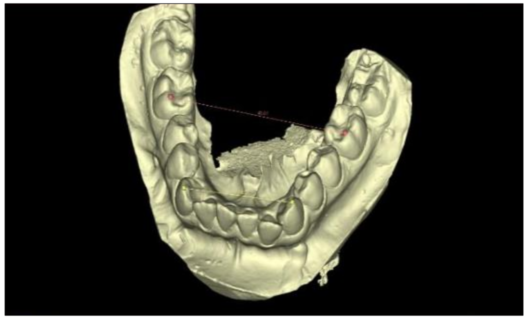
Figure 2 CBCT analysis

Digital study models were taken in STL format, as well as CBCT. For the UPenn analysis the CBCT was used, however, in this study a small modification was made in the location of the maxillary points, measuring from the external cortex of the first permanent molars at the level of the furca and not at the level of the Mx point. In the lower jaw the measurement was made the same as in the UPenn analysis (Fig. 2). In the analysis of the models proposed in the study, digital models in STL format were used, which were evaluated by applying the Korkhaus and Wala Ridge analysis. In the case of the Korkhaus analysis, the anteroposterior arch length represented by the distance between the contact points of the upper central incisors and the point located in the center of the maxillary fissure at the level of the premolars and molars was determined [10].

Table 2 Study variables

Variable	Definition operational	Type	Classification	Indicator categorical	Scale ofmeasurement
Analysis orthodontic	Diagnostic methods using in the study in order to approach to the final diagnosis, determining the relationship between the amount of space required for that all the teeth they can to line up of way correct	Independent	qualitativeNominal	digital models Korkhaus analysis Analysis of wala ridge Tomography computerized of makeconical Analysis of Penn	1 2 3
Age	Years compliments of the patients that make up the sample study	Independent	quantitativediscreet	Years 21-27	1
Sex	Differentiation between masculine andfeminine of the sample	Independent	qualitativeNominal	Male Feminine	1 2
Discrepancy transversal	Deficiency transverse jawsthat present the models that are part of the sample study	Dependent	quantitativeKeep going	Predictive value of the test Positive Negative	one 2

Source: author



Source: Author

Figure 3 Intermolar width measurement, digital technique

For the Wala Ridge analysis, the distances between the centers of the clinical crowns at the height of the canines, premolars and molars were compared with the distance between the projections of these points on the mucogingival line (fig. 3) right to left of both upper and lower first permanent molars, using the Nemocast 3d software tools [11].

2.1.2. Statistical and results analysis

With the information obtained, a database was prepared in an Excel Office 2021 spreadsheet and then exported to SPSS. To calculate the averages of the measurements, the comparison and correlation between the measurements in models and in CBCT was performed using nonparametric statistics (Table 7 and 8). On the other hand, to determine the validity of the diagnostic analyses, the predictive values of the positive test and the negative test were calculated. As a result, when comparing the values of the measurements between model and CBCT data, the difference was found to be statistically non-significant in all the measurements evaluated (Table 7).

The results were analyzed statistically using the SPSS program, applying the Kolmorov-Smirnov test to evaluate the normality of the distribution of values in order to determine the use of parametric tests (T-Students or ANOVA) or nonparametric tests (Mann Whitney U or Kruskall Wallis) with a significance of 5% and a reliability level of 95%.

Then when performing correlations between model and CBCT measurements, it was found that the correlation is significant in 5 out of 7 measurements, only in the initial maxillary data and in the maxillary difference data.

3. Results

The sample used was 30 people, where 38% were men and 63% women. The age range was 21 to 27 years. The average age was 22.35 years, and 85% were between 21 and 23 years old, and 15% between 24 and 27 years old (see table 3).

Table 3 Data on the sex and age of the individuals included for the analysis of the cross-sectional discrepancy between models

Sex	Mean ± S.D	Min.	Max.	f -%
Male	1,60±0,50	14,00	34,00	10 (33%)
Female				20 (67%)
Age				
21 to 23 years old	21,13 ±5,86	14,00	34,00	24 (80%)
24 to 27 years old				6 (20%)

Source: author

Transverse discrepancy in cone beam computed tomography was established using Pennsylvania analysis. Where the upper part had a mean of 65.38±5.08 and the lower part 62.54±3.60 (see table 4).

Table 4 Descriptive data in cone beam tomography by Pennsylvania analysis

Penn Analysis	Media	D.E	Min.	Max.
Superior	65.38	5.08	50.20	72.60
Inferior	62.54	3.60	45.00	70.41
Difference (Upper - Lower)	4.90	3.80	-10.00	12.00
Discrepancy	2.73	1.90	2.00	4.00

Source: author

For the determination of the transverse discrepancy in models, the Korkhaus and Wala Ridge analysis was used, where a greater discrepancy could be seen with the Korkhaus analysis with 1.20±0.59 over the Wala-Ridge analysis with 1.11±0.36 (see Table 5).

Table 5 Cross-sectional descriptive data in virtual models using Korkhaus and Wala Ridge analysis

		Media	D.E	Min.	Max.
Wala Ridge Analysis	Superior	46.27	4.19	28.70	56.20
	Inferior	44.15	3.41	28.30	50.50
	Difference (Upper - Lower)	2.12	2.32	-6.00	6.00
	Discrepancy	1.11	0.36	1.10	3.00
Korkhaus Analysis	Superior	36.50	6.48	34.30	40.2
	Inferior	31.60	3.44	30.10	37.7
	Difference (Upper - Lower)	4.90	3.04	-4.20	3.00
	Discrepancy	1.20	0.59	1.00	3.00

Source: author

To compare the results of the cross-sectional discrepancy obtained from the model and tomography analyses, the normality test with the Kolmogorov-Smirnova was used. It was evidenced that it does not come from a normal distribution since the p-value was <0.05 (see Table 6).

Table 6 Normality test

Normality tests Kolmogorov-Smirnova.			
		Statistician	p- value
Descriptive	Age	0.500	0.000
	Sex	0.182	0.000
	Superior	1.117	0.002
	Inferior	0.077	0.156
Penn Analysis	Difference (upper-lower)	0.093	0.032
	Discrepancy	0.091	0.040
	Superior	0.126	0.000
	Inferior	0.136	0.000
Analysis of Wala Ridge	Difference (upper-lower)	0.485	0.000
	Discrepancy	0.384	0.000
	Superior	0.164	0.000
	Inferior	0.083	0.000
Khorkaus Analysis	Difference (upper-lower)	0.77	0.146
	Discrepancy	0.73	0.000

Source: author

With the nonparametric Kruskal Wallis test, it was found that there is a significant difference p-value <0.05- (see Table 7).

The Mann Whitney test showed that there is a difference in Penn's test in relation to Wala-Ridge and Korkhaus (see Table 8).

The variables such as sex and age were reviewed and it was sought if they are related to the discrepancy, however, it was found that they do not exist (see table 9).

Table 7 Statistical test of between-group comparison of the discrepancy of the STL digital model and computed tomography

Kruskal Wallis	N	Media	D.E	95% CI		p- value
Penn Analysis		1.83	0.90	1.645	1.915	0.000
Wala-Ridge Analysis		1.33	0.384	1.224	1.412	
Korkhaus Analysis		2.26	0.73	1.235	1.385	
Total		2.603	2.741	1.419	1.488	

Source: author

Table 8 Statistical test for comparison between groups of the discrepancy between the digital model and the computed tomography using the Mann Whitney test

Mann Whitney		Difference of means (I-J)	95% CI Min.		p- value
Penn Analysis	WalaRidge Analysis		0.24	0.71	0.00
	Korkhaus Analysis	0.39	0.18	0.67	0.00
WalaRidge Analysis	Korkhaus Analysis	-0.04	-0.24	0.17	0.852

Source: author

Table 9 Statistical test for the review of the existence of the difference in the discrepancy of models and computed tomography with age

Kruskal Wallis test		N	Media	D.E	95% CI		p-value
					Min.	Max.	
Penn Discrepancy	21 to 23 years old		1.80	0.82	1.36	1.91	0.931
	24 to 27 years old		1.84	0.85	1.35	2.23	
	Total		1.83	0.83	1.41	1.91	
Wala-Ridge discrepancy	21 to 23 years old		1.25	0.51	1.14	1.36	0.123
	24 to 27 years old		1.40	0.65	1.24	1.37	
	Total		1.32	0.58	1.22	1.42	
Korkhaus Discrepancy	21 to 23 years old		1.36	0.75	1.18	1.54	0.99
	24 to 27 years old		1.36	0.71	1.18	1.44	
	Total		1.36	0.73	1.24	1.48	

Source: author

The same result was observed for sex, where there was no significant difference (see table 10).

Table 10 Statistical test for the review of the existence of the difference in the discrepancy of models and computed tomography with sex

Kruskal Wallis test		**N**	**Media**	**D.E**	**95% CI**		**p-value**
					Min.	**Max**	
Penn Discrepancy	Female		1.927	0.94	1.43	2.00	0.992
	Male		1.720	0.93	1.44	1.99	
	Total		1.7	0.93	1.44	1.89	
Wala-Ridge discrepancy	Female		1.22	0.48	1.12	1.40	0.554
	Male		1.25	0.53	1.10	1.32	
	Total		1.29	0.57	1.02	1.35	
Korkhaus Discrepancy	Female		1.18	0.68	1.12	1.32	0.123
	Male		1.32	0.63	1.09	1.40	
	Total		1.26	0.70	1.14	1.38	

Source: author

4. Discussion

One of the main objectives of orthodontic treatment is the certainty of a diagnosis in order to be able to carry out an adequate treatment. Tamburrino et al.(12) establish in their article the parameters, benefits, disadvantages and limitations of two scientifically validated cross-sectional analyses: Wala Ridge analysis in models and Penn analysis in CT scans. However, they do not make a comparison between them, but rather, with the collection of information, it is appreciated that the Penn tomographic analysis has the most benefits and the fewest limitations. This is supported in turn by the systematic review by Sawchuk et al, and the study by Miner et al, where they conclude that cross-sectional analyses performed on CT scans present greater diagnostic accuracy, taking into account their sensitivity and specificity.

In spite of the good reproducibility results obtained in the digital model with the software or 3D, systematic errors were observed, especially in the dental size measurements. The error found in canines may be due to the position they occupy in the dental arch, which hinders the movement of the digital model in the program and the identification of reference points used to perform the measurements. Factors such as point identification, model manipulation and dental morphology may also be related to the presence of systematic errors.

Several studies have been carried out to analyze the transverse measurements of the jaws. Therefore, the variability of the results are compiled in the different investigations and it is clearly defined that the diagnosis of malocclusions should be made in the three planes of space, since the certainty of a good diagnosis leads to an adequate treatment. In relation to this Tamburrino et al. [12] in their publication present three cross-sectional diagnostic methods without categorizing them, one using postero anterior radiography based on Ricketts frontal cephalogram analysis, a second analysis using study models proposed by Andrews, known as Element III and a third analysis proposed by the University of Pennsylvania using cone-beam computed tomography (CBCT), the authors' proposal in this article is clearly to provide the readers with these diagnostic tools to be incorporated into the daily practice of cross-sectional analysis no matter which one is chosen, but always keeping in mind the objectives in mind [12].

In this study, the analysis on digital models showed good reproducibility and reliability, however, some difficulties were detected during the use of the program. Errors when recording the images, presence of shadows, poor definition in the mesiodistal diameter of anterior teeth with diastemas and in the cusps are some aspects that should be improved in future versions of the program or 3D.

On the other hand, Miner et al [9, 13] carried out a study to determine the sensitivity and specificity of tomographic analysis (CBCT) to determine maxillary widths, they established that this method has a high percentage of sensitivity and specificity. Sawchuck et al [14] to evaluate the skeletal and dental transverse deficiency concluded that tomographic analysis is the most reliable method to evaluate the transverse deficiencies of the maxilla. Therefore, in the present proposal, tomographic analysis and digital analysis of STL models with Nemocast software were used and it was established that CBCT is the most reliable method when measuring transverse diameter.

In addition, based on the results, it could be observed that there is a significant correlation between this diagnostic proposal based on models and the CBCT analysis. A strength of this proposal lies in the fact that it does not require an additional complementary examination such as a tomography (CBCT), since with the usual records such as the study models a transversal deficiency can be diagnosed, in addition to being a fairly convenient and quick method to perform. By taking the dentogingival junction as a reference, which is presented in the digital models, it makes it easier for the clinician so that at the time of measurement there is no major distortion of the measurements obtained, since it is a fairly objective point. However, it is necessary to mention that, like all of them, this analysis also has its limitations, such as the fact that it could not be applied in case the first molars are: absent, with large rotations, very marked vestibulo-lingual inclinations and large gingival recessions. However, it is a perfectly extrapolable alternative for the vast majority of the population who seek orthodontic treatment.

In this study we were able to determine the transverse discrepancy in STL format models by means of the Nemocast program using two Khornaus analyses whose positive predictive value is 10% and 84% for Korkhaus, the positive predictive value was 10% and 84% for the negative predictive value, indicating a diagnostic validity of 94%, while when applying the Wala Ridge analysis the diagnostic validity demonstrated was 84%, corresponding to 3% for the positive predictive value and 81% for the negative value; [15] therefore we can specify the high reproducibility of the STL models that even more today have changed the way of making the diagnosis, making it in a simpler way and obtaining results similar to those obtained when using plaster models, improving the working time and optimizing the development of the diagnosis and execution of the treatment.

Finally, from the results presented in this work regarding the correlation between this model analysis proposal and the Tomographic analysis, it can be inferred that both methods are equivalent when diagnosing the cross-sectional dimension. In addition, there is no relationship between age and sex to measure the cross-sectional discrepancy, therefore there is no statistically significant difference in the results of this research

5. Conclusion

The Nemocast software performed well in terms of reproducibility, reliability and validity in the measurement of tooth size and transverse distances. However, the transverse discrepancy determined on digital models by Korkhaus and Wala Ridge analysis reported a diagnostic validity of 94% and 84%, respectively.

Although the measurements performed with CBCT analysis and Nemocast software showed statistical differences, the magnitude of this difference is considered clinically irrelevant.

The sample is defined as insufficient and is therefore termed a low evidence study.

There is a statistically significant correlation between the CBCT values and the STL model analysis in the Nemocast software proposed in this work, however the tomographic analysis (CBCT) used to determine the maxillary widths, has a high percentage of sensitivity and specificity, to evaluate the skeletal and dental transversal deficiency. Therefore, it can be said that the tomographic analysis is the most reliable to evaluate the transverse deficiencies of the maxilla, so it is applicable for the diagnosis of the transverse dimension.

Compliance with ethical standards

Acknowledgments

We thank all the participants included in the study who gave us their consent to carry out the research.

Disclosure of conflict of interest

The authors agree no conflict of interest

Statement of informed consent

Informed consent was obtained from all individual participants included in the study.

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