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A Comparative Study of Reproducibility, Reliability and Accuracy in Measuring Mesiodistal Tooth Size Using Four Different Methods — 2D Digital, 3D CBCT, 3D Segmented and 3D Intraoral Scanner Method

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Additional information is available at the end of the chapter

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1. Introduction

The first challenge we face in a patient receiving orthodontic treatment is making a correct diagnosis. It involves several issues such as clinical examination, radiographs, photographs and study models. The fusion of these sources of information provides a basis for planning and performing orthodontic diagnosis and appropriate treatment.

Model studies are an important diagnostic tool to develop an appropriate treatment plan. Plaster models can three-dimensionally and accurately reproduce the patient's dentition and also make accurate measurements with greater ease and accessibility of the patient's own mouth. We could assess tooth sizes and tooth shapes, the positions of the teeth and the shape of the dental arch. We can also carry out the calculation of the Discrepancy Index and Bolton Index, and finally, we can determine the occlusion in all three planes of space — sagittal, transverse and vertical.

Some of the problems associated with traditional study models are with regard to processing and physical storage. These problems limit their use in clinical practice. In addition, it is an effort for the clinician manual to do measurement of study models, because many professionals omit these measurements before the start of orthodontic treatment. They only measure the size of the upper lateral incisors, becuase these are the teeth that suffer more variation in shape and size.

The introduction of new technologies that digitalize these study models in two dimensions (2D), and even more new devices that créate models in three dimensions (3D) makes possible to eliminate traditional models, creating quickly, easily and accurately 2D or 3D models. On these new models we could calculate all measures directly on the computer models that are already in clinical routine for the vast majority of orthodontists.

Similarly, the appearance of two new techniques for patient records both the cone beam computed tomography (Cone Beam Computed Tomography or CBCT) and the appearance of intraoral scanner, have been a breakthrough in dental diagnosis and specifically in orthodontics.

The introduction of cone beam computed tomography (CBCT) provides higher spatial resolution images with high quality using shorter scan time (10--70 seconds) in order to have lower radiation than conventional CT (TC) [1]. The field of orthodontics allows us to make a more accurate diagnosis, avoiding conventional radiographs and providing information of orofacial structures in the three planes of space.

During the last decade, CBCT has been used specifically for the maxillofacial region to implant placement and in the study of impacted teeth, especially third molars or canines. But there are many possibilities offered, such as the study of the airway, or three-dimensional cephalometric study, among others.

The intraoral scanner enables us to obtain digital models in three dimensions that are more accurate than digital models in two dimensions. This new tool also allows us to obtain three-dimensional images of the teeth and can perform measurements on them without the need to realize traditional study models. Using the scanner 3D models we can avoid radiology tests, such as CBCT, that entails radiation.

Both CBCT and intraoral scanner, allow us to obtain undoubted clinical and useful applications, as well as many amenities that are a revolution in orthodontic diagnosis and may go to slowly replace traditional methods of study models in orthodontics. But before that, it is important to know the characteristic features and limitations of these new tools.

2. Digital method

With the great development and the incorporation of digital imaging, either a conventional scanner or digital cameras, many clinicians digitized images of conventional models for taking measurements.

With the advent of computer programs in orthodontic clinics, new methods of measurements came in that was based on digital analysis of two-dimensional (2D) images obtained more accurately and quickly. Once the data is entered, all the required calculations can be performed.

With many of them, it is necessary to send impressions or study models of the patient. Companies are the responsible for scanning them with their subsequent destruction and therefore the received all the images scanned. These digital models avoid professional having

to store. Some companies give you the chance to get the digital image of the model in different materials such as plaster, acrylic or other materials.

In our study, the Digital method used was Ortodig, designed by a researching group of the University of Valencia, whose reliability and reproducibility had been tested previously [2-4]. This method performs a digital scanning of plaster study models obtained from alginate impressions by a conventional scanner (Figure 1).

Figure 1. Guidance and scanning study models in the scanner in the Digital Method.

Upper and lower models of the patient were digitalized independently. Each digitalized image was stored in the computer. The image (Figure 2) is centred and surrounded by a graph paper, while the buttons with the different functions of the program are on the right side of the image. Above these buttons, we can see the image of the model selected in small size, and the name.

Before taking any measurements, but within the software, we performed a calibration for each image of each model to find the real dimensions in milimeters, avoiding discrepancies associated with different magnifications because of the digitalization process, even if the process has been made by the same operator (Figure 3).

In this case, to perform this calibration, arches are digitalized surrounded by a conventional graph paper that we place around the model, in order to know the magnification suffered by the model [5].

Once the models are calibrated, we can proceed to measure the mesiodistal size of the teeth.

This size corresponds to the maximum distance between the contact points in their proximal, mesial and distal surfaces.
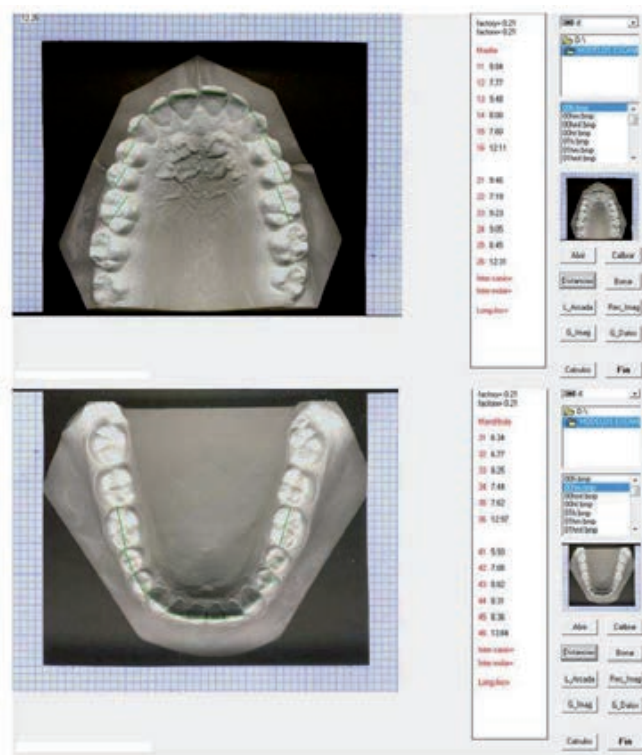
Figure 2. Digital models 2D

Figure 3. Digital Model calibrated.

Hypothetical points of contact are measured at their proximal, mesial and distal surfaces in malpositioned teeth. On each of the images taken and already calibrated, is located mesial and distal contact points for each tooth, corresponding to the maximum mesiodistal size. The program Ortodig draws automatically a green line among these marked points. Also, we can see the result of the real size in milimeters next to each tooth.

3. 3D CBCT method

The introduction of cone beam computed tomography (CBCT) in the late 90s was a major step in orthodontic imaging. The CBCT provides higher spatial resolution images with high quality using shorter scanned and lower radiation than conventional CT [1]. In the field of orthodontics, it allows us to make a more accurate diagnosis and provide us information of orofacial structures in three planes of space. Similarly, we can obtain three-dimensional images of the teeth and we can perform measurements on them that we usually did on both study models and 2D digital models.

The CBCT allows us to obtain very useful and easy clinical applications, which represent a revolution in orthodontic diagnosis and may go on to slowly replace traditional image technologies. In the future, we could get in a single diagnostic register (CBCT) panoramic radiograph, lateral cephalometric, posteroanterior cephalometric and study models, which are the tools commonly used in orthodontics, as well as the ability to visualize infinite images that we could not get any other way.

CBCT scan uses a low-energy anode within a fixed tube-ray beam using a cone-shaped to capture the image and obtains a data volume of cylindrical or spherical described as FOV (field of view). FOV are of variable sizes and CBCT scanners of large volume (for example, i-CAT) are able to capture the whole skull. Some CBCT scanners also allow you to adjust the height of the cylindrical FOV to capture just one area, reducing the radiation dose. The limited volume CBCT scanners can capture a data volume of 40 mm high and 40 mm in diameter, similar to the width and height of the periapical conventional radiography. Acquisition times with CBCT vary between 10 and 40 s depending on the type of scanner used and the selected exposure parameters.

The three-dimensional volume of data is acquired during a single sweep of the scanner, using a simple and direct connection between radiation source 2D rotate synchronously around the patient's head and sensor. Depending on the type of scanner used, the X-ray tube and detectors rotate from 194º to 360º, taking in each grade one or two images around the patient's head. CBCT scan the patient's head sitting or standing. The projection is orthogonal, indicating that the X-rays are parallel to each other. Measurements can be made at 1: 1, and the object is close to the sensor, resulting in little effect of projection error.

With CBCT we obtained different images from a single scan, it is a dynamic record. Furthermore, it has managed to reduce the effective dose of radiation absorbed by the patients and the time of exposure, compared to TC.

The 3D images are composed of voxels instead of pixels like 2D images, this means that the pixel will have a third side.

The CT voxels are anisotropic (not identical in all drawings), the height depends on the thickness of the voxel (slice thickness), which limits the accuracy of reconstructed images in planes determined (e.g., in the sagittal) as it depends on the distance between said cuts (gap) in the acquisition schedule. But with CBCT data, voxels are isotropic (equal in length, height and depth), which allows a geometrically accurate measurements for CBCT data in any plane.

Each pixel of the images we get from scanning represents a value of attenuated radiation, which is measured in Hounsfield units (HU). The value 0 corresponds to the value of the radiation attenuation of water, and the value of -1000 HU air. The scale starts at

-1000 HU and ends in 3000, with the whole range of those used to express the image information numbers.

Data is stored in a format established by the National Electrical Manufacturers Association, called DICOM (digital imaging and comunications in medicine), which allows users to share pictures although they have different devices.

The CBCT used in the study was the Dental Picasso Master 3D ® (EWOO technology, Republic of Korea., 2005) (Figure 4). It allows to obtain quick three-dimensional images of all craniofacial structures.

Figure 4. Dental Picasso Master 3D®.

3D images obtained are stored in dicom format, varying the size of the data files that generates up to 450 megabytes depending on the scanned area.

Once we obtained the patient´s CBCT, we can have two options for obtain 3D CBCT models:

3.1. 3D CBCT method

Firstly, it is necessary to guide the patient's head as it suits us, so we can see what best incisal edges and occlusal surfaces in an axial section of the volume (3D skull) of the patient, to proceed with measurements.
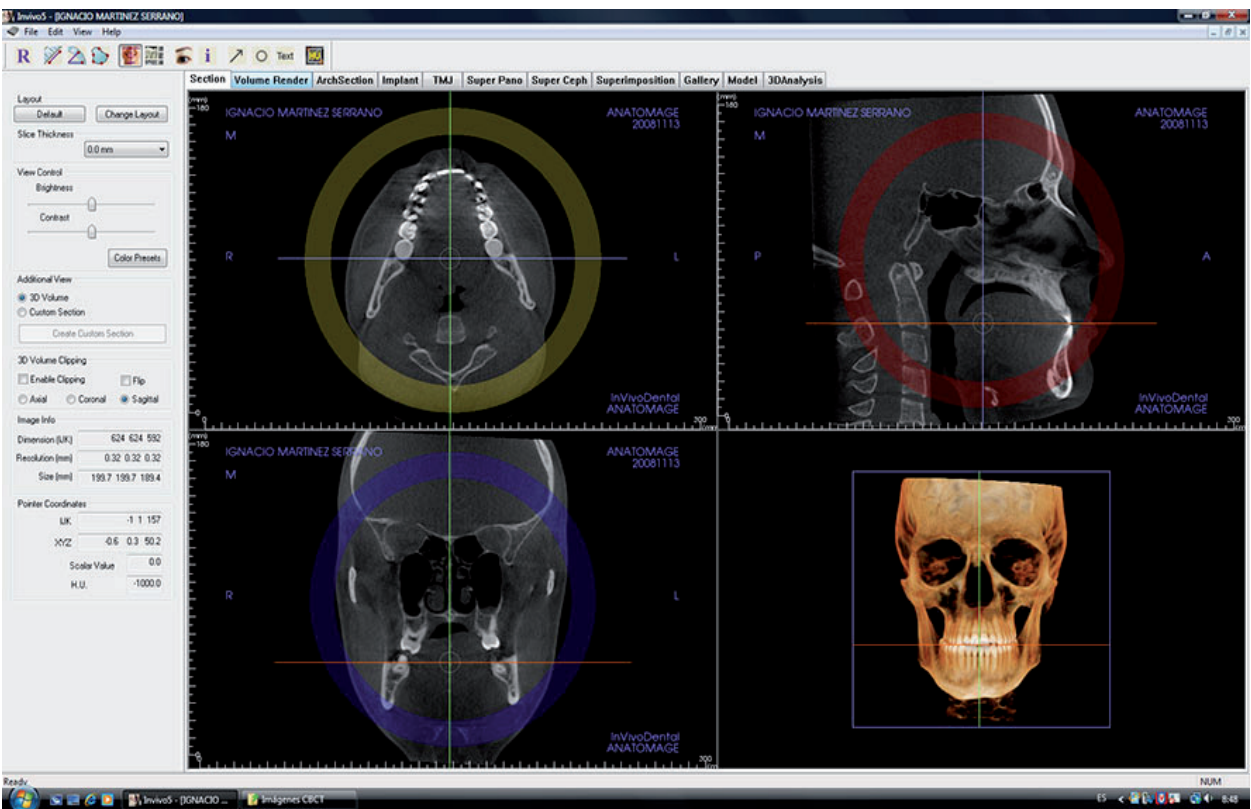

Figure 5. Orientation of the patient's head.

In Figure 5, we can see the axial cuts (upper left panel), sagittal (upper right), coronal (lower left) and the image of the volume of the patient (lower right).

Once the patient's head is oriented, we have to select the volume, and on this we perform an axial cut at the level of the incisal edges and occlusal surfaces of the maxillary teeth in order to make measurements on an occlusal view. Once we have finished with the upper arch, we do the same in the lower arch. The images can be extended to have a better view of the teeth (Figure 6). We do not have to perform a calibration of the images as they are in real size (1: 1).

The use of axial slices of the arches among teeth with CBCT avoid the segmentation of three-dimensional models to perform measurements of the arches. Segmentation of CBCT is

Figure 6. On the left, the axial scut of the maxilla; and on the right, the occlusal view.

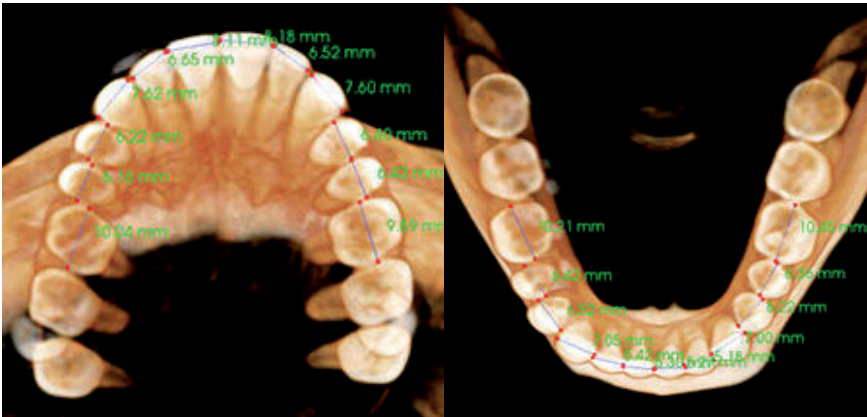expensive because we have to send the CBCT to a specialized company to do so, assuming an extra expense.

Figure 7. Measurement of the upper and lower mesiodistal sizes of 3D CBCT models.

After selecting the appropriate axial slice, we have to select the option of the program that allows us to make linear measurements. Using the computer mouse we select the contact points of each tooth and automatically a red purple line appears between those points corresponding to the maximum mesiodistal tooth size. The result of measurement is shown in millimeters on the side of each tooth as seen in Figure 7.

3.2. 3D CBCT semented method

Once we have the CBCT´s patient, we have to open with InVivoDental 5.0 software to send it in dicom format securely through the website of the company Anatomage®.

The company Anatomage® segments images. The segmented CBCT can be downloaded through their website a few days later. Segmentation is the separation of the corresponding voxel to each structure: teeth, bone and other structures, divided into groups. In this case, the voxels visible are only the voxels that create teeth.

Figure 8. Oclusal views 3D CBCT Semented.

In Figure 8, we can observe the upper and lower 3D model of the selected patient obtained by CBCT 3D method. The image can be moved in all directions and we could select the upper or lower models separately, in order to to enlarge each of them. The program also allows us to remove the bone and even select or remove a teeth in order to help us perform measurements in case of a lot of crowding (Figure 9).

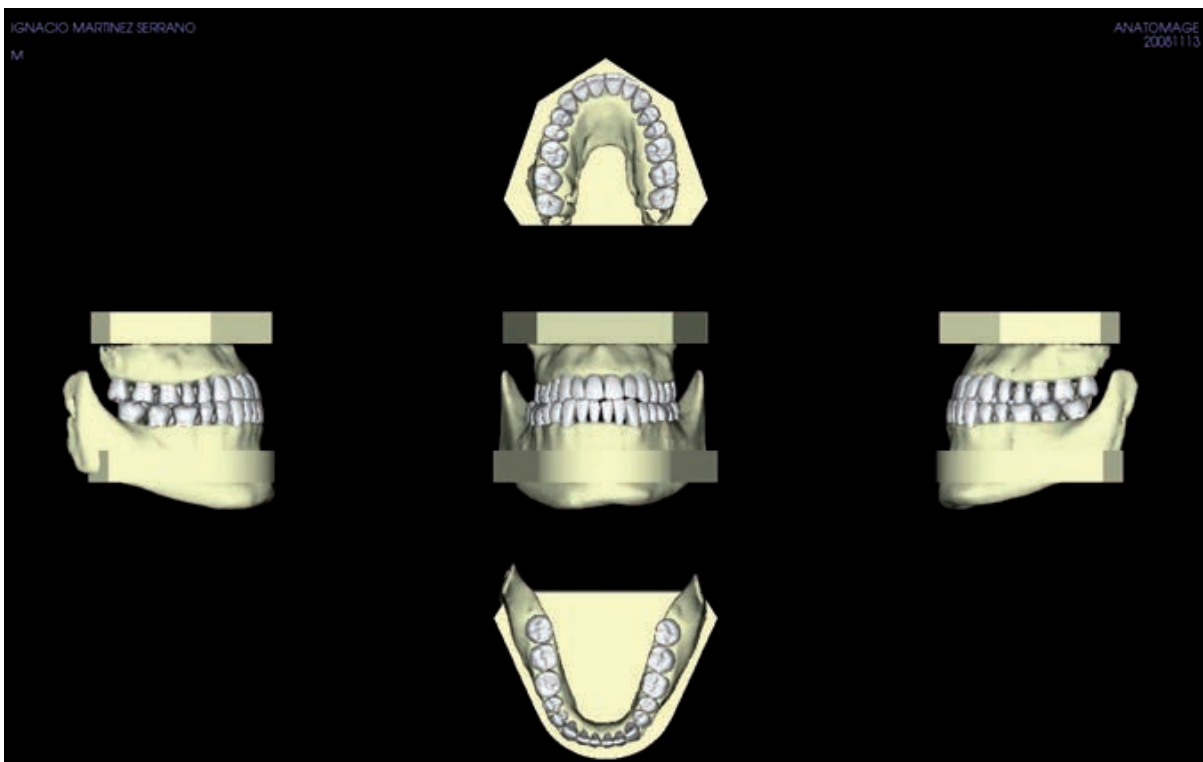You will not need a calibration of the images as they are in a real size, unlike the Digital Method.

Figure 9. CBCT Semented Model.

To measure mesiodistal tooth sizes we start from the first molar and go to the other first molar, first upper and then lower arch.

We select the program option that allows us to measure linear measurements. We select the contact points of each tooth Using the computer mouse that automatically show red purple line appearing between those points that correspond to the maximum mesiodistal tooth size. The result of measurement is shown in millimeters on the side of each tooth as we can see in Figure 10. The program offers the option to edit or delete the image if the maximum size is not correct.

If we have malpositioned teeth, we can accurately measure proximal contact points; mesial and distal, because if the adjacent teeth measurement limit us the view, we can remove it temporarily.
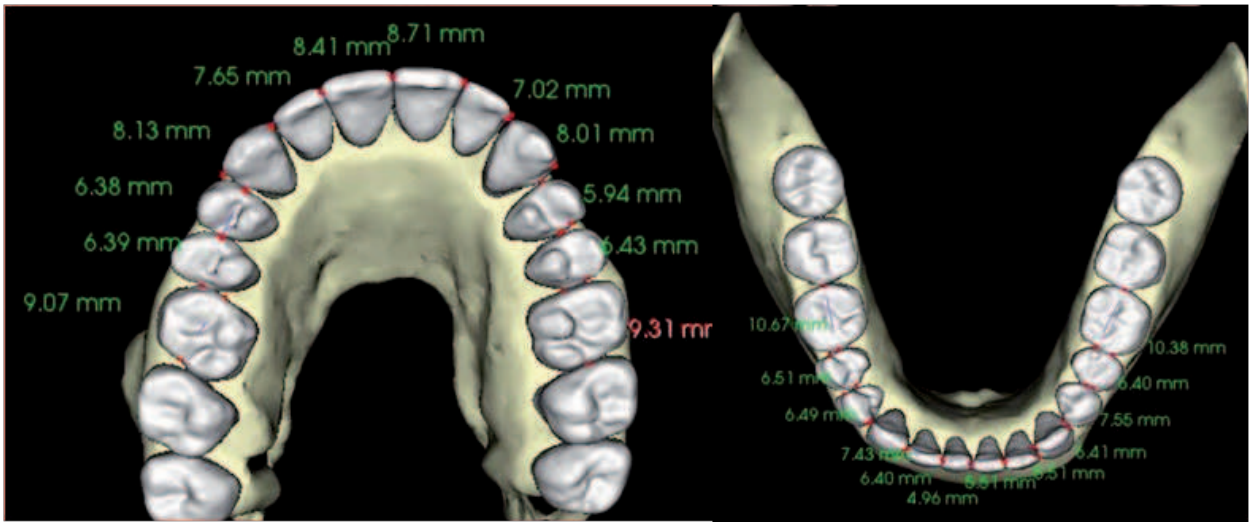

Figure 10. Measurement of the upper and lower mesiodistal sizes in a 3D CBCT Semented model.

4. 3D Itero® intraoral scanner method

With Itero scan, study models are obtained directly from scanning the mouth of the patient without taking impressions of alginate or other plastic material. Optical scanners are divided into two types. The first type are the scanners that capture individual images of the dentition, as iTero®. In a single image it could capture normally about three teeth. To obtain the three-dimensional model, a series of individual images are taken and they are assembled by a software creating a virtual three-dimensional model. The scanner camera is positioned at different angles to ensure that it accurately captures the entire crown of the teeth and not just an occlusal view. The software draws areas that are not viewed by the camera in order to complete the missing data in the virtual model. These drawn areas do not adversely affect the final image.

Figure 11. iTero® Intraoral Scan.

The second type of the optical scanner is also called intraoral camera, which is the new video scanner. These optical scanners work just like any video camera that records the teeth while the camera is moving inside the mouth. The more the teeth are digitalized, the bigger the virtual model will be created by the software.

The intraoral scanner used in this study was iTero® (Cadent Inc., Carlstad NJ) (Figure 11). It was first marketed in 2007 and it uses a technique of parallel confocal image acquisition. It is a unit consisting of a computer monitor with a keyboard to add patient data, a handpiece comprising a laser beam which is the fundamental part, from which intraoral images are obtained and are activated by a pedal. The images obtained are collected in the processing unit and then sent for storage to the database of Cadent® in Carsltad.

To perform a digital 3D imaging by intraoral scanner iTero®, it is necessary to have five scanning areas: occlusal, lingual, buccal and interproximal contacts of the adjacent teeth. To scan the lingual and buccal areas, we have to place the surface of the scanner´s head 45 ° to dental structures (Figure 12). However, to scan the occlusal surface of a tooth it is necessary to place the scanner perpendicular to the occlusal tooth. When all these different scans are completed, a record of the patient's occlusion is performed in three points while the patient is occluding in centric relation. Generally, a complete scan of the upper and lower arches and the record of virtual bite usually takes about 5 minutes. When digital scanning has been completed, the software has a number of image enhancement tools that can provide a clearer picture of the patient's dentition.
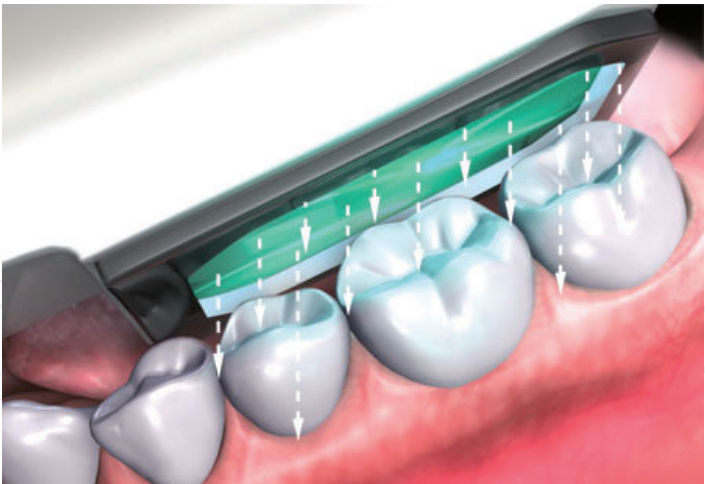
Figure 12. Scanner head position relative to the dental structures.

Once the scan is completed, we need a software to analyze images from the intraoral scanner iTero®. The software used is OrthoCad® (Cadent Inc, Carlstad NJ). This program is free for users of iTero®. The model could be visualized from all angles with it (Figure 13), both the occlusion model or the two separate arches. The software allows direct measurements on 3D model and indirect measurements calculated directly showed in a simple table.
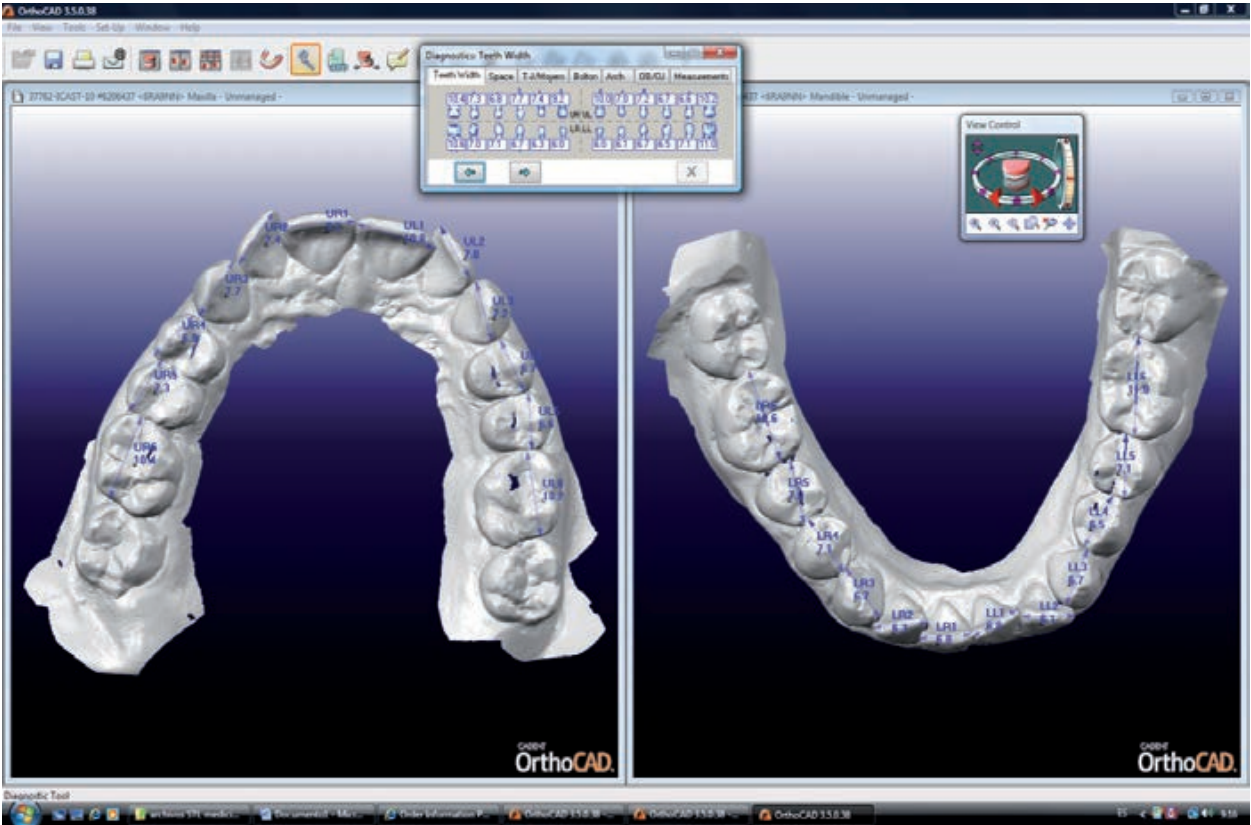

Figure 13. Occlusal view 3D iTero® Intraoral Scan model.

5. Advantages and disadvantages of methods

The three-dimensional models have multiple advantages over physical plaster models, such as sharing them with other professionals from anywhere in the world for diagnostic opinions. Also, we do not have the problem of physical storage, as it does not occupy much space for storing them for years. Moreover, there is no risk that they may lose or break. But these advantages are shared with other methods of obtaining digital models, it is convenient to focus on the advantages and disadvantages of each method.

Among the advantages, with the scanner 3D models and 3D CBCT models (both segmented and non-segmented) images are dynamic. Images can be moved, rotated, zoomed, flipped, cropped and measured without loss of information, which is not true images of 2D method that it is a still a single image. Another advantage shared by all the 3D models is that it is possible through specific softwares (and usually costly) to perform virtual set-ups quickly and fairly simple to help you decide the treatment plan.

Also both types of models can be shared online with colleagues because the images are in a format that allows to be properly displayed and used by other users, the only difference is that the file type in the case of segmented models is a DICOM file and in the case of 3D scan models are STL files.

The main advantage of the 3D scanner models versus 3D CBCT models is that we do not irradiate the patient with the scan, we scan the dental arch using a laser light that is incident on the patient's teeth without causing any radiation or alteration in oral tissues.

Other advantage of 3D scanner models is that the software used to measure the models obtained by intraoral scanner are usually free and easy to access and installation with the user key you provide to buy the scanner. Besides these programs (such as OrthoCad®, Cadent) are easy to handle and complete enough to perform linear and other measures for diagnosis in orthodontics. However, professionals employing segmented models in their offices, need to purchase more expensive softwares such as Invivo® or Nemoceph®, because softwares are included when the purchased CBCT scans are simple viewers, too basic for measurements as those used in orthodontic diagnosis.

Finally, with 3D scan models we can see the soft tissues that cannot be seen in the 3D CBCT models.

Like in all techniques, 3D models also have disadvantages. The main drawback is the cost of the scan unit iTero® and the CBCT scan and the software necessary for its operation. Another drawback is that both scans usually occupy enough physical space. Itero need an area in the same room but CBCT needs to have another room to accommodate it with security measures to avoid radiation.

In both cases, a professional is needed to perform intraoral scanning, as well as to use the handpiece scanner and software.

The main advantage of 3D models CBCT over the others is the ability to measure the teeth that are included. However, with 3D scanned models it is not possible, therefore we should take as reference the contralateral tooth, but sacrificing reliability measures.

Another advantage is that we can get 3D models from CBCT, and all diagnostic records: orthopantomography, and lateral and frontal radiography. However, with the scan we will need to take x-rays of the patient, since on scanned models we could not see only cranial structures.

Finally, another disadvantage from Itero® Scan is the time to obtain the scanner, which is between 45 and 15 minutes depending on the skill and experience of the operator, while the time it takes to perform a CBCT is between 6 and 3 minutes, depending on equipment acquisition. Most of the time, patient discomfort is worse with the scan. Patients should follow the orders of the operator and turn the head and open the mouth usually for a prolonged period, especially for subsequent scanning sectors. Not all patients tolerate this, in fact those with limited opening or joint pain describe it as annoying.

6. Comparison of the four methods for measuring dental sizes

6.1. Material and method

In order to compare all the methods, 53 patients (28 women and 25 men) were selected from the Orthodontics Department of the University of Valencia, with a mean age of 30.22 years (Table 1).

	TOTAL	MEN	WOMEN
MEAN	30.22 years	25.9 years	33.9 years
RANGE	10.6-58.75 years	10.6-55.2 years	11.6-58.75 years

Table 1. Sex distribution of the patients.

The following were abtained from all the patients:

• Digital models obtained from digitalized traditional models.

• 3D CBCT models and 3D CBCT segmented models.

• 3D intraoral scan model from the patient's mouth scanner.

Inclusion criteria were:

• Permanent dentition up to the first molar.

• Absence of abnormalities in tooth number and shape.

• Less than 6 mm (positive or negative) of discrepancy index.

• Good quality of plaster study models.

• Absence of large occlusal restorations or prostheses.

After obtaining the four types of models, we proceeded to study the measurement of tooth sizes (Figure 14).
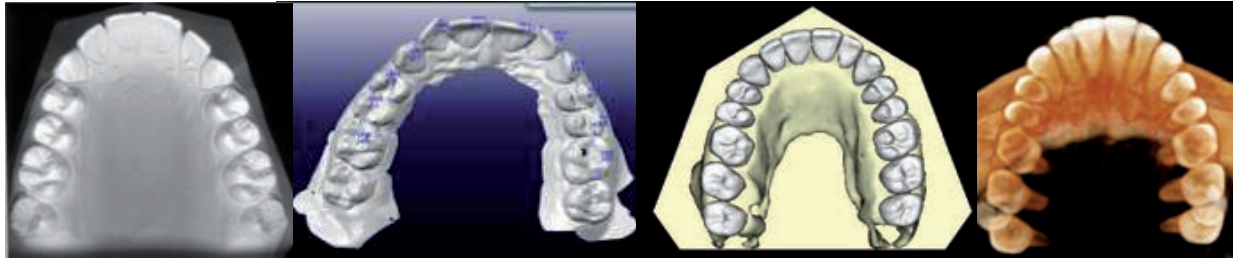

Figure 14. Upper model obtained using the four methods: 2D Digital, 3D iTeroTM intraoral scanner, 3D Segmented and 3D CBCT method.

The mesiodistal size corresponds to the maximum distance between the contact points in their proximal, mesial and distal surfaces. The second and third molars were excluded. Hypothetical points of contact were measured at their proximal, mesial and distal surfaces in malpositioned teeth.

All measurements were performed by the same observer previously trained. Intraobserver error was calculated. Out of 53 patients in the study, 15 were randomly selected and the same observer remeasured each direct measurements on 3 occasions with an interval of 1 week between each. The error was less than 0.012 mm with a coefficient of variation (CV) of 1.08%.

To calculate interobserver error, a second observer, also trained in orthodontics, measured 3 times each of the measurements with a weeks interval between measurements in the 15 patients previously selected. The error was less than 0.04 mm with a coefficient of variation (CV) of 1.4%.

All calculated measures were stored in an Excel spreadsheet and analyzed using SPSS v.15.0 for Windows.

The statistical tests were applied to compare means of paired measurements and the study of correlation between variables, through the analysis of regression lines and correlation coefficients.

The discrepancy between the methods was calculated as the difference between the average value of each specific point for each method in comparison with the mean value of the parameter measured by the digital method and expressed as a percentage.

7. Results

When evaluating tooth sizes using the four methods, we observed that there are statistically significant differences among them.

If we consider as 'gold standard' 2D digital method, we note that for measuring tooth size, 3D scanner models tendency to underestimate the smallest tooth sizes, as in the case of lower incisors and canines. However, when the tooth sizes are bigger as is the case of the first upper and lower molars, 3D scanner iTero® tends to overestimate the values of the 2D method (Figure 15).
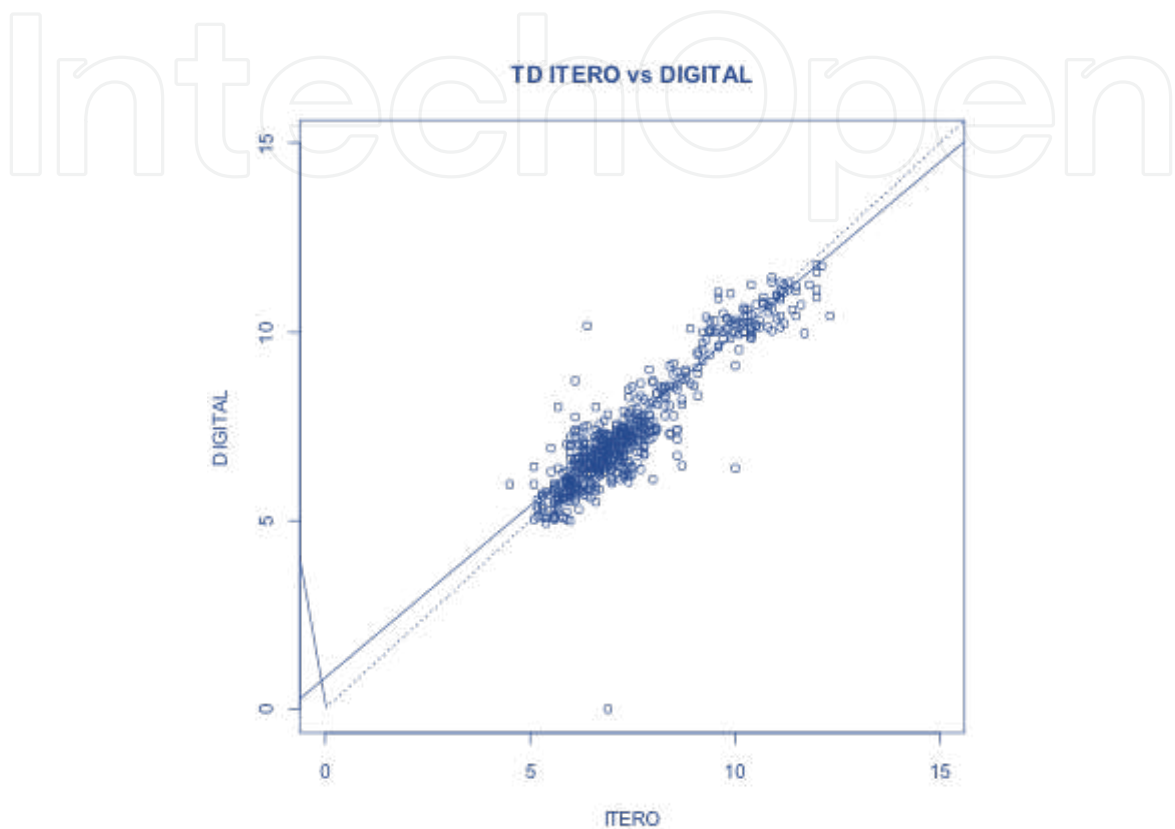

Figure 15. Scatterplot of points in which the measurements of tooth sizes for 3D Scanner Method versus 2D Digital Method are compared.

If the values of the 3D CBCT segmented method and 2D digital method are compared, there is a tendency for the 3D CBCT segmented method to underestimate generally tooth sizes compared to 2D digital method of all teeth. Results were higher for the teeth of the lower arch (Figure 16).

When we compared the two 3D techniques: 3D Scanner Method and 3D CBCT segmented Method, 3D Scanner Method tends to underestimate the tooth sizes with small values and overestimate large values, these differences were more pronounced at the level of the lower arch (Figure 17).

Finally, when comparing the 2D Digital Method with 3D CBCT unsegmented Method, we could see that by measuring the teeth in both the upper and lower canines and upper central incisors, 3D CBCT unsegmented Method usually obtains higher values than 2D Digital Method. But the trend is reversed when we measured left lateral incisor, except tooth 12 where there were no differences between both Methods (Figure 18). Therefore, we found statistically
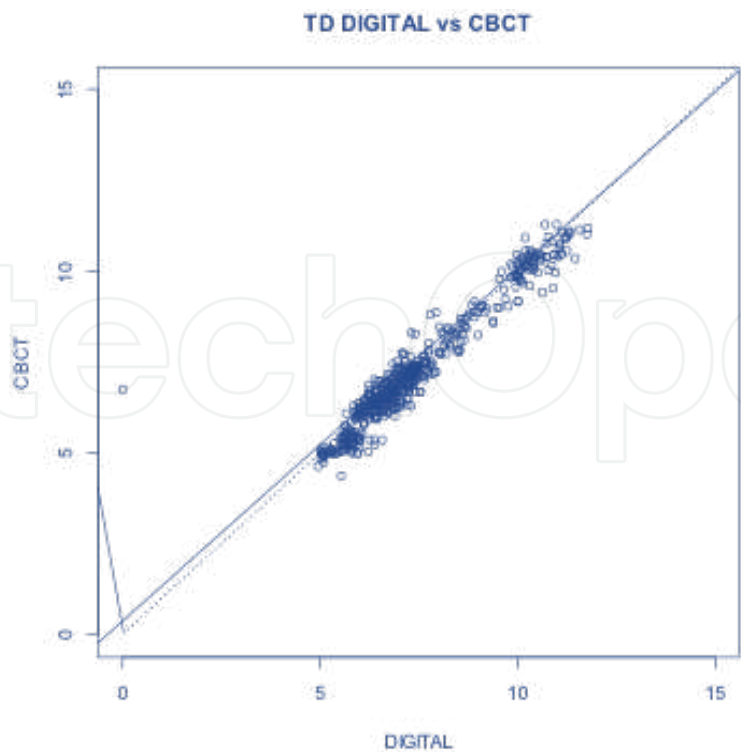
Figure 16. Scatterplot of points at which measurements of tooth sizes 2D digital Method for 2D versus 3D CBCT segmented Method are compared.
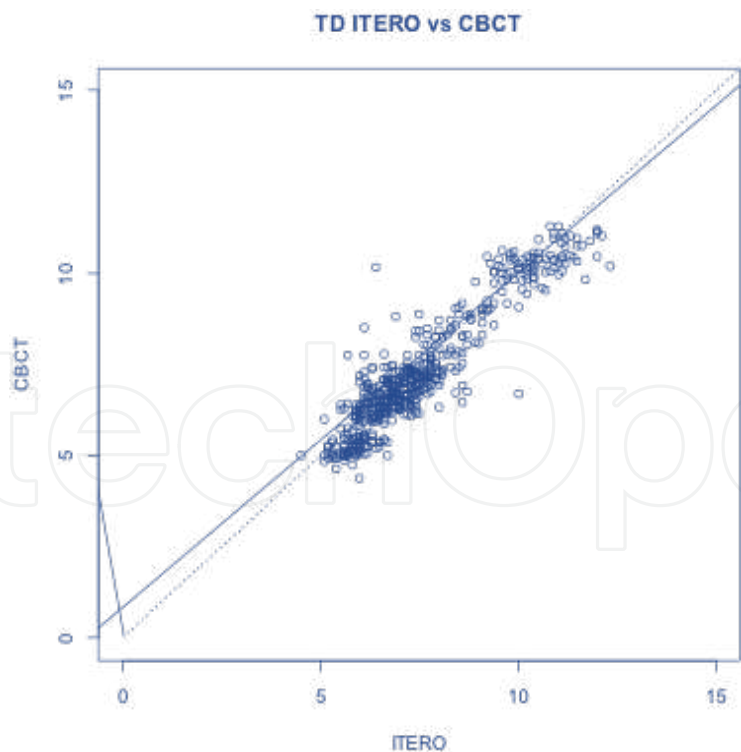

Figure 17. Scatterplot of points in which the measurements of tooth sizes for 3D Scanner Method versus 3D CBCT segmented Method are compared.
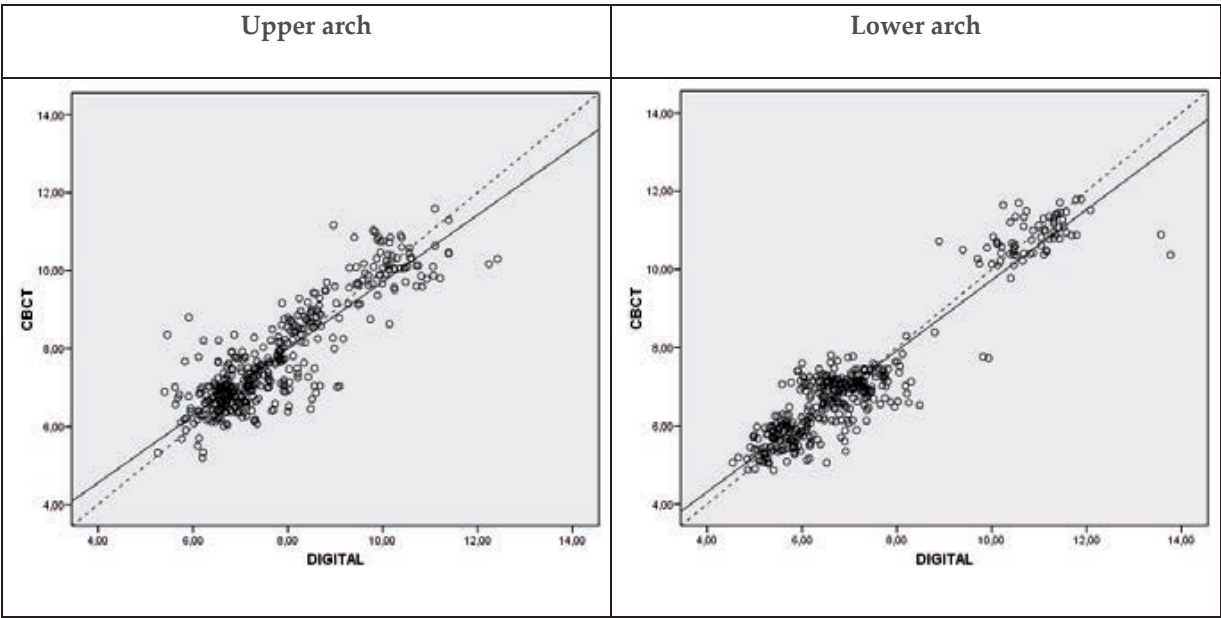
Figure 18. Scatter plots of points at which measurements of tooth sizes for 2D Digital Method and 3D CBCT unsegmented Method are compared.

significant differences that make 3D CBCT unsegmented Method unsuitable for measuring tooth sizes.

8. Discussion

We have compared the results obtained in this study with other studies of similar methodology [6]. Tarazona et al. compared 27 models obtained by segmentation of CBCT and those same 27 models obtained by a 2D digital method, identical to the one performed in this work, obtained a good intra-examiner reproducibility and a high correlation between both methods, as has been obtained in this study. For the tooth size measurements, we also obtained similar results: 3D CBCT segmented models tend to underestimate tooth sizes, however this has no clinical impact if we perform calculations like discrepancy index or Bolton index.

Kau et al. in 2010 made the comparison of 3D CBCT segmented method with other digital method [7], with whom we fully concur in his finding of underestimation of teeth sizes by the CBCT 3D segmented method, they justify ensuring that models segmented from a CBCT have interproximal contact rounded teeth due to the difficulty in capturing the CBCT technology to register anatomic contact points which cause, when mesiodistal measurements performed, the operator has a clear place mesial or distal position the limit the tooth. We have experienced exactly what these authors explained in their study.

There are also matches of this study with the study of Sousa et al. published in 2012 [8] and those of Naidu and Freer 2013 [9]. In both studies, they found the high reproducibility of the scanner iTero® 3D models, also for them is higher than with other physical or digital 2D

methods. They also found an underestimation in tooth sizes and arch lengths by 3D scanner method.

Other studies like that of Wiranto 2013 et al. [10] supported the results of the subestimation of dental mesiodistal sizes with 3D CBCT segmented method, but these authors only obtained subestimation in the upper arch, not in both arches like our study.

Our results agree with those obtained by Akyalcin et al. in 2013 [11] who reported obtaining more inter-examiner reproducibility with 3D Scanner method than with other methods and a higher magnification of the measurements made with 3D CBCT segmented method.

However, our results differ from those obtained by Cuperus et al. in 2012 [12], who obtained a magnification of some measures by the intraoral scanner iTero® contrary to our study. We also do not agree with Flügge et al. [13] who found no difference between the 3D CBCT segmented method and 3D scanner method.

Finally, there is no article in the literature that analyzes the dental size 3D CBCT non-segmented. One possible explanation may be the industriousness that comes with having to find appropriate axial slices for performing measurements of tooth sizes.

9. Conclusions

Based on the results obtained in our study, we can establish the following conclusions:

- The results of the mesiodistal size measured with the digital method and the three-dimensional method (CBCT) are very similar showing hardly no clinically significant differences.

- The 4 methods are simple, rapid and accurate to determine direct measurements of the dental arch such as mesiodistal tooth sizes.

- It has been proved that the intra and inter-examiner reproducibility is very good for measuring mesiodistal sizes.

- the accuracy and reliability of 3D Scanners are clinically acceptable method for tooth sizes; although there is a tendency to overestimate measures smaller teeth as incisors and lower canines.

- When comparing methods we can say that the accuracy and reliability of CBCT 3D Segmented Method are clinically acceptable for tooth sizes, although there is a tendency to overestimate measures in the lower arch.However, accuracy and reliability of CBCT 3D unsegmented Method are not clinically acceptable for tooth sizes; underestimated since some teeth and other overestimate the real size of the teeth.

- Finally, the Digital Method 2D, the 3D CBCT Segmented method and 3D scan method are perfectly valid for measuring Orthodontic tooth sizes.

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