



# The Effect of Random and Systematic Errors in the Measurement's Outcomes of Tooth Size Arch Length Deficiency by Two Different Measuring Tools

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## Abstract

**Introduction:** No orthodontist can deny that cast analysis is so important key in diagnosis and treatment planning in conjunction with the rest of routine orthodontic records. Cast analysis for permanent teeth is one of the influential aids to obtain the exact amount of space required to relieve the crowding properly via adequate space gaining methods such as extraction, IPR (Interproximal Reduction), expansion, or distalization. Therefore, the measurement errors during tooth size arch length analysis are a crucial issue because any decrease or increase in millimeters for space required may cause significant alterations in treatment plan strategy because of the inaccuracy of measurement's magnitude. So, answering the following question is so interesting. The question is "ignoring the measurement errors during cast analysis measurement can affect the measurement's outcomes significantly or not. Despite, studying and understanding the measurement errors that could happen during cast analysis procedure is so equal to cast analysis study especially for orthodontists.

**Aim of the Study:** to study the effect of random and systematic errors in the measurement's outcomes of tooth size arch length deficiency by two different measuring tools (digital caliper and Exocad 3D CAD software).

**Materials and Methods:** 10 examiners chosen from orthodontic postgraduate students were committed to measure the tooth size arch length deficiency (TSALD) for 3D printed upper and lower models with full set of permanent dentitions with absence of wisdom teeth by two different measurement techniques in two different situations. The first status referred to the examiners will measure the TSALD by digital caliper (0.02 mm accuracy) and medical 3D image-based engineering software (Mimics software) without knowing or understanding the measurements errors that could happen during reading, recording and collecting the measurements. In addition, they did not recognize that they are incorporated in the study. The first status is denoted by a Double-Blinded group (DB). The second status referred to the examiners will measure the TSALD by the same two different measuring tools with complete knowing and understanding the measurements errors and their effects on the reliability and validity of the study. The second status is denoted by the Control Base group (CB).

**Results:** Wilcoxon signed-rank test was used to assess a paired difference test (P Value) of the same 10 examiners on the same maxillary and mandibular 3D printed model and/or 3D surface solid CAD model. The P value of TSALD of maxillary and mandibular arches via digital caliper were statistically insignificant in DB and CB group. Paired difference test of TSALD of upper and lower arches via mimic 3D software were irrelevant significance in both groups.

**Discussion:** The statistical analysis was summed up using mean, standard deviations, median, and range of TSALD measurements of the maxillary arch (MAX) and mandibular arch (MAN) on DB and CB groups. Wilcoxon signed-rank test was used to assess a paired difference test (P Value) of the same 10 examiners on the same maxillary and mandibular 3D printed model and/or 3D surface solid CAD model. The P value of TSALD of maxillary and mandibular arches via digital caliper were 0.169 and 0.445 respectively which indicated that the statistical differences were insignificant in DB and CB group. Additionally, Irrelevant paired difference data for the P value of the TSALD of MAX and MAN arches via digital software were 0.285 and 0.445 subsequently.

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**Conclusion:**The findings indicated that the direct impact of the measurement mistakes in this experiment was not statistically apparent, despite the environment of measurement errors being present in the Double-Blinded group and the devaluation of measurement errors in the Control-Base group. However, the use of extremely accurate calibrated measuring instruments, the removal of any irrelevant variables (Bias) and skilled TSALD examiners (procedural approaches) in both groups from the beginning may have an advantage over measurement mistakes.

**Acknowledgement:**Special sincere thanks and appreciation for all orthodontic staff, residents, and postgraduate student for their great help and support to finish the study.

**KeyWords:** Transparent Plastic Arch Form Ruler, Reflex Metro-graph, F-curve Ruler.

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## Introduction

No orthodontist can deny that cast analysis is so important key in diagnosis and treatment planning in conjunction with the rest of routine orthodontic records<sup>(1)</sup>. Gaining space to move the teeth in the correct position at the end of orthodontic treatment is the main goal for all orthodontic practitioners<sup>(2)</sup>. Hence, cast analysis for permanent teeth is one of the influential aids to obtain the exact amount of space required to relieve the crowding properly via adequate space gaining methods such as extraction, IPR (Interproximal Reduction), expansion, or distalization. Therefore, the measurement errors during tooth size arch length analysis are a crucial issue because any decrease or increase in millimeters for space required may cause significant alterations in treatment plan strategy because of the inaccuracy of measurement's magnitude<sup>(3)</sup>. There were many measurement tools to assess tooth size arch length deficiency in a plaster model such as a Transparent ruler and divider, Digital caliper<sup>(4)</sup>, Sliding caliper<sup>(5)</sup>, Brass wire<sup>(6)</sup>, Transparent plastic arch form ruler<sup>(7)</sup>, Reflex metro-graph<sup>(8)</sup>, F-curve ruler<sup>(9)</sup>, Segmented arch length<sup>(10,11)</sup>, Indirect archwire<sup>(12)</sup>, Smart mobile<sup>(13)</sup>, Photogrammetry<sup>(14)</sup>, and 3D software program ( 3 Shape Ortho Analyzer)<sup>(15)</sup>. A digital caliper was the most popular and straightforward tool for arch length analysis. In addition, 3D software packages were the most modern and user-friendly tool for arch length measurements. Fortunately, the results of the two approaches' measures were both accurate and repeatable, and the disparities in dental measurements obtained by the two procedures were not clinically significant<sup>(16,17)</sup>. Even though the two processes differ in many ways, such as Human versus digital. Both procedures had their own errors in measurements variability. therefore, the source and extent of the error were more crucial than the errors themselves<sup>(18)</sup>. The measurements errors are comprised of three main categories: (1) Gross (Human or Blunder) error, (2) Random (Casual or Residual

error, and (3) Systematic (Non-Random) errors. Errors in reading instruments, recording, and calculating measurement findings are referred to as Gross errors. These errors can be avoided by two means: - (1) Great care is a must in reading and recording the data. (2) Even more than two readings should be taken. Hence, the availability of multiple examiners could reduce the magnitude of gross errors. Random and systematic errors are the most typical types of scientific method errors<sup>(19)</sup>. By repeating measurements of the same quantity under the same conditions, random error can be identified such as the difficulty and/or inaccuracy in identifying or defining certain points in dental casts. Random errors can be reduced not eliminated by taking an average of many readings. When a measurement is consistently under or over-estimated due to instrumental, environmental, or observational error. it is referred to as systematic error. The use of proper techniques, calibrated equipment, and the use of standards can all help to eliminate systematic error. Systematic errors of a large magnitude shift the results in one direction. While large random errors indicate difficulties in duplicating the measurements.<sup>(20)</sup>. The aim of this study is to determine the effect of random and systematic errors in the measurement's outcomes of tooth size arch length deficiency by two different measuring tools (digital caliper and Exocad 3D CAD software).

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## Materials & Methods

### Design of the Study

Selected cross-sectional study.

### Sample Size

10 examiners were chosen from postgraduate (Master and Ph.D.) students and residents in the orthodontic department- Faculty of Dentistry- El-Minya university. They were committed to measure the tooth size arch length deficiency for 3D printed



upper and lower models with full set of permanent dentitions with absence of wisdom teeth by two different measurement techniques in two different situations. The first status was done first then followed by the second status. The first status referred to the examiners will measure the tooth size arch length deficiency (TSALD) by digital caliper (0.02 mm accuracy, Baxevanos F.&M. Co., 15 Christodoulou Petridi. Naoussa 59200. Greece) and medical 3D image-based engineering software (Mimics software, Materialize NV, Leuven, Belgium) without knowing or understanding the measurements errors that could happen during reading, recording and collecting the measurements. In addition, they did not recognize that they are incorporated in the study. The first status is denoted by a Double-Blinded group (DB). The first status is denoted by a Double-Blinded group (DB). The second status referred to the examiners will measure the TSALD by the same two different measuring tools with complete knowing and understanding the measurements errors and their effects on the reliability and validity of the study. The second status is denoted by the Control Base group (CB).

### Characterization of the Digital Model

The researcher chose one STL file from the digital records of the orthodontic department of faculty of dentistry- El Minya University. Regarding to American Board of Orthodontics digital model and 3D printing requirement, the criteria of this record were as the following:

- The mesh topology should have ordinary pattern of ramification. It means they each vertex of tessellation pattern is presented by a fan of triangles that forms a full disk or a half disk.
- The mesh topology should have a sound surface model. That is, the model cannot have any digital gaps or holes. A maximum of one digital hole (which corresponds to the border of the surface model) is permitted in the mesh topology for digital models without bases.
- The tessellation pattern of the mesh topology should have no intersection among the triangles. It means that no triangle may "pass through" the face of another triangle.

- The labi gingival tissues should be demonstrated on all models (at least 6-12 mm).
- The palatal rugae and tuberosity in maxilla and retromolar pad in the mandible should be included in the scan.

### Characterization of the Physical (3D Printed) Model

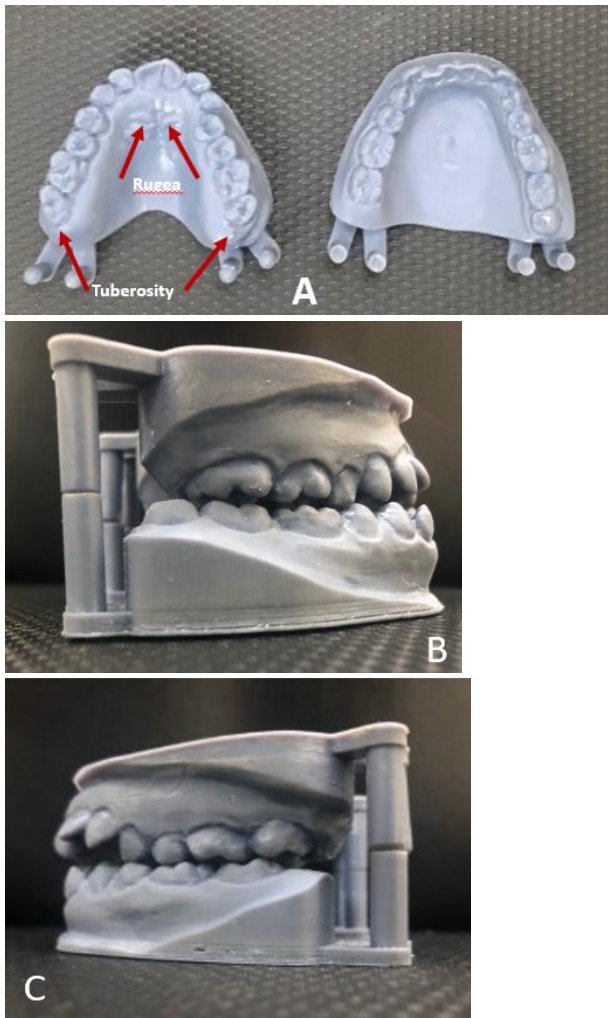
After choosing the STL file who fulfilled the aforementioned inclusion criteria, the digital model was 3D printed by Formlabs Stereo Lithography Apparatus (SLA) 3D printer (Form 2, Serial Name: Adjective animal, Somerville, Massachusetts, USA) (Fig. 1). The criteria of inclusion were fulfilled by the following requirement (Fig 2):

- Full set of permanent dentitions from the second permanent molar on one side to second permanent molar to other side.
- Full anatomical structure of dentitions without any defect in morphology or anatomy of dentitions such as fractures, caries, dental anomalies or restorations.
- There was no evidence of mechanical, chemical, physical wearing.
- Severe or high moderate dental crowding, spacing, severe or moderate rotations were exclusion criterion.
- Normal gingival contour and texture.

Furthermore, 10 printed upper and lower 3D printed models were given to each examiner.



Fig.1. Form2 SLA 3D printers



**Fig.2.** Showing the 3D printed model, (A) the occlusal view of upper and lower model, (B) Right side in occlusion, and (C) Left side in occlusion

**Methods**

Carveth Read quoted that it is better to be vaguely right than exactly wrong <sup>(21)</sup>. The preceding claimed that it can be justified by the idea that lowering measurement errors is preferable than error prevention. Avoidance of all errors in any study cannot be done practically during measurements procedures. So, reducing measurement errors is the only and mandatory way to be applicable in all research. The objective of the study is to compare practically and statistically the effect of reducing measurement errors in this study. As previously mentioned, this study is comprised of two groups, one of them are done with all possible ways to reduce measurement errors (Control Base group (CB)) and the other one is without measurement error reduction and without knowing that they were incorporated in the study double-Blinded group (DB)).

**Double-Blinded Group (DB)**

In the beginning of the study, the selected 10 examiners were known only by the researcher and requested to do TSALD measurements via digital caliper on only one 3D printed model and 3D EXOCAD software on solid surface CAD prototype of the same printed model (Fig.3). Each examiner was received two copies of table that were quoted from R N. Staley and N T Reske 2011 <sup>(22)</sup>. Tabular illustrations of each copy were shown in (Fig. 4). They commenced the measurement procedures as the following:

- They were unaware that they were included in the study. We let them know that we were doing a practical quiz in the permanent dentition analysis.
- The available arch length in both arches using both measurement tools should be obtained using segmented arch length technique, according to the researcher's instructions.
- There were no fixed measurements techniques among the examiner to obtain the mesiodistal width of the dental units and the arch length by segmented techniques.
- They were not enlightened by measurements errors and its effect on the reliability and the validity of any study.
- There were no standardized steps and double check during measurement procedure among the examiners.
- They were under the researcher's control during all measurement processes and recording the data using both measuring tools.
- The measurements procedures were not done under controlled conditions.
- The researcher started to inform the examiner that you are included in this study after collecting the data spontaneously.
- Following ethical regulations, a verbal and non-verbal detailed description of the study hypothesis and its objectives were explained for each examiner who had agreed to participate in the study and a written consent was signed by the examiner.



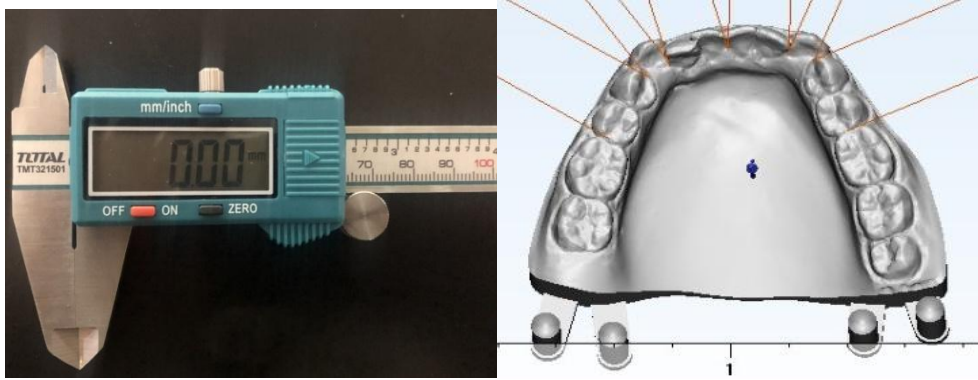


Fig.3. Showing the digital caliper and the 3D surface solid CAD prototype of lower dental model

**TOOTH SIZE AND ARCH LENGTH ANALYSIS**

POST GRADUATE INITIALS:                      DATE: / / 2021.  
 TIME:    DIGITAL CALIPAR (SB GROUP)

MESIODISTAL WIDTHS OF PERMANENT TEETH					
MAXILLA			MANDIBLE		
RIGHT	TOOTH	LEFT	RIGHT	TOOTH	LEFT
	U1			L1	
	U2			L2	
	U3			L3	
	U4			L4	
	U5			L5	
	TOTAL			TOTAL	
TOTAL UR=UL -			TOTAL LR=LL -		

	MAXILLA		MANDIBLE	
	RIGHT	LEFT	RIGHT	LEFT
1-ANTERIOR REGION				
2-CANINE REGION				
3-POSTERIOR REGION				
4- ARCH LENGTH (SUM=1+2+3)				
5- TOTAL MESIODISTAL WIDTHS				
6-DISCREPANCY (SUM= 4-5)				
TALD				

**TOOTH SIZE AND ARCH LENGTH ANALYSIS**

POST GRADUATE INITIALS:                      DATE: / / 2021.  
 TIME:    3D CAD SOFTWARE (SB GROUP)

MESIODISTAL WIDTHS OF PERMANENT TEETH					
MAXILLA			MANDIBLE		
RIGHT	TOOTH	LEFT	RIGHT	TOOTH	LEFT
	U1			L1	
	U2			L2	
	U3			L3	
	U4			L4	
	U5			L5	
	TOTAL			TOTAL	
TOTAL UR=UL -			TOTAL LR=LL -		

	MAXILLA		MANDIBLE	
	RIGHT	LEFT	RIGHT	LEFT
1-ANTERIOR REGION				
2-CANINE REGION				
3-POSTERIOR REGION				
4- ARCH LENGTH (SUM=1+2+3)				
5- TOTAL MESIODISTAL WIDTHS				
6-DISCREPANCY (SUM= 4-5)				
TALD				

Fig.4. Copy of tables that were given the examiners of Double-Blinded group

**Control-Base Group (CB)**

Before giving the two copies of tables to the same selected 10 examiners, they should know the following:

- Dental cast analysis.
- Measurements errors.
- Types of measurement errors.
- The effect of measurement errors in the reliability and validity of the study.

- How to reduce measurement errors
- Reliability and validity.
- Types of reliability and validity

The following precautions were strictly applied during the measurement procedures to reduce the amount of measurement errors<sup>(23,24,25,26)</sup>:

1. Well trained examiners even before the training and education course were chosen



- to prevent human errors (Gross and random error reduction)<sup>(27)</sup>.
2. Selecting appropriate measuring tools and proper calibration to avoid inherent limitation of the devices (instrumental systematic error reduction).
  3. Zero adjustment of the digital caliper was checked every two measurements to avoid poor initial adjustment (instrumental systematic error reduction).
  4. Holding the digital caliper with water mark to avoid apparatus abuse (instrumental systematic error reduction) (Fig.5).
  5. Wrong observation or reading the measuring tools was reduced by presence of second observer (observational systematic error reduction) (Fig.6).
  6. To minimize different repeated readings to the same size using water mark to fix the hand position during measuring the object (observational random error reduction).
  7. In case of different readings of the same object can be minimized by taking the of two different reading (observational random error reduction).
  8. In addition. Double check by presence of second observer during measuring, calculating, recording, and collecting the data was so helpful to slow down the human errors (gross and random error reduction) (Fig.7).
  9. Standardization of the measurement procedures:
    - B. the mesiodistal crown diameters were measured following this sequence, the maxillary and mandibular central, lateral incisors, canines, and first and second premolars
    - C. The arch length was calculated by segmenting it into six straight segments. Six segments made up the measurement of the arch length from the mesial surface of the first permanent molar on the right side to the mesial surface of the first permanent molar on the left side. The sum of the segments was equal to the arch length.
    - D. The second observer was present to control and review many procedures such as reading, recording, calculating, .....etc.
  10. After data Collection. The researcher was double checked the data thoroughly (Gross error reduction).

#### *Test-Retest Error*

All the examiners examined the test again after a one- two weeks break to compare the results with the initial measures to guarantee the reliability of measurements. No statistically significant difference between the first and second readings was found, according to the paired-sample t-test ( $p > 0.1$  and  $SD \pm 0.014$ ). Between the first and second readings, Pearson's correlation coefficient showed a strong association (0.99).

#### *Data Analysis*

After data collection and tabulation on Excel (Microsoft Office, Windows 10), data management and statistical analysis were conducted using the Statistical Package for Social Sciences (SPSS Inc., Chicago, IL, USA). Descriptive analysis (Mean, SD, Median, Range) was done. Wilcoxon signed rank test was used to get the P-values of both measuring tools (Digital caliper and Exocad 3D CAD software program) for both groups (Single-Blinded and Control-Base groups). Bland-Altman Upper and Lower Limits of Agreements, Pearson's correlation, and 95% CI of differences between digital caliper and digital software was performed on both groups (DB group and CB group).

Most of the following standard steps was applicable on both measurement techniques.

- A. Regarding to hunter and priest <sup>(28)</sup>, using gently the tips of the beak of the digital caliper held to parallel to occlusal plane, the mesiodistal width of the crown was measured on the 3D printed model as the maximum distance between the proximal surfaces of the teeth (Fig.8). The 3D software EXOCAD program eventually accepted the same technique to measure the mesiodistal widths of the teeth (Fig.9 & 10).

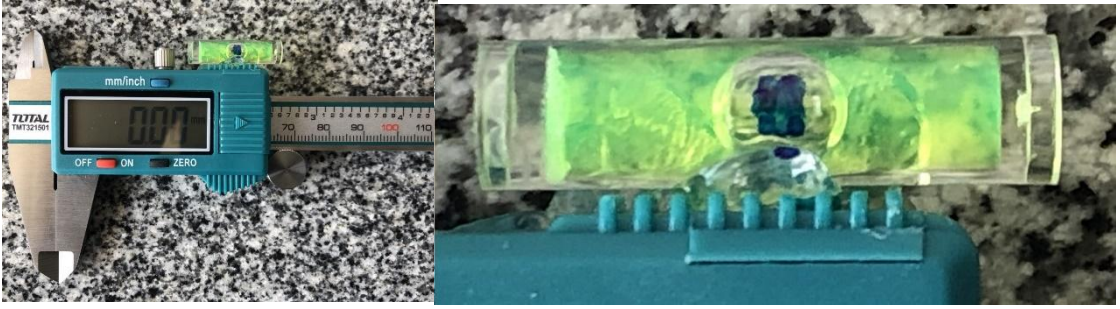


Fig.5. Showing water mark attached to digital caliper



Fig.6. showing the presence of the second observer within DB group during the measurement procedures by both measuring tools

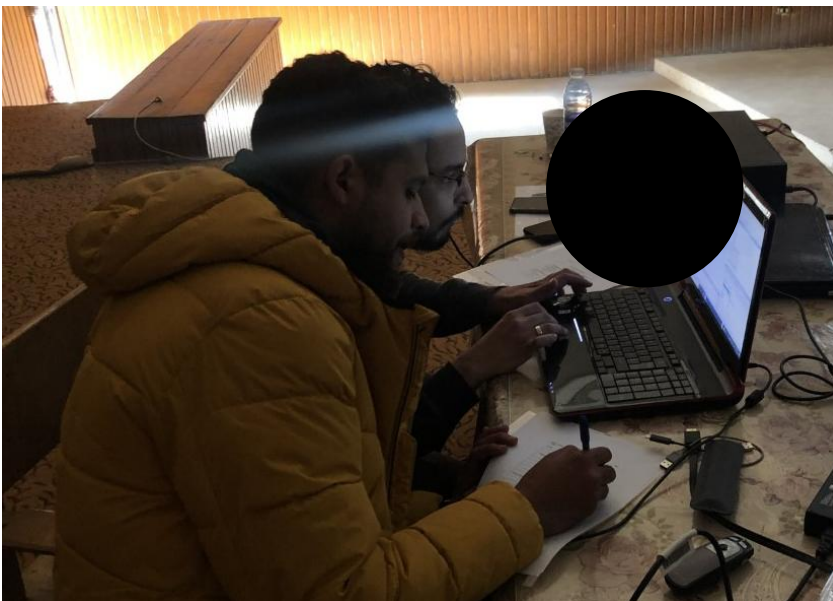
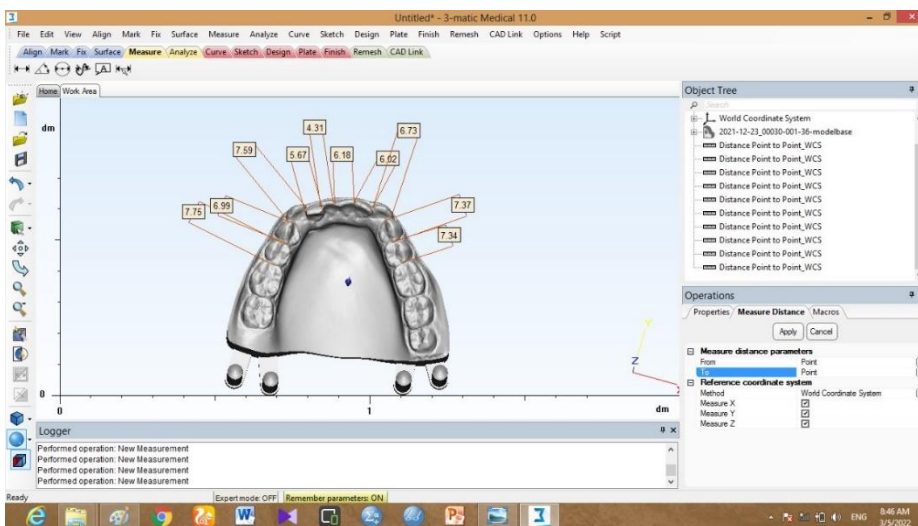


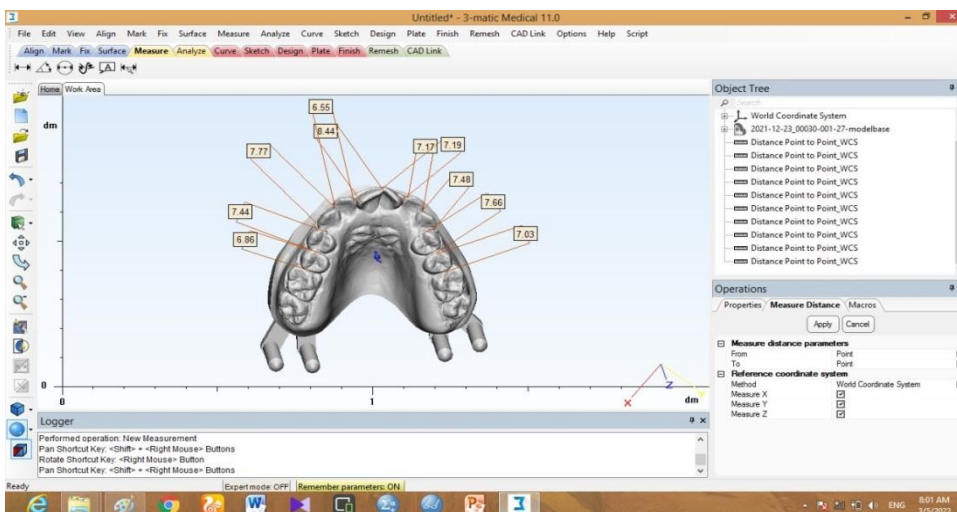
Fig.7. Showing the presence of the second observer within DB group during checking and writing down the numerical values of the measurement procedures by Exocad 3D CAD software measuring tool.



**Fig.8.**Showing the digital caliper with centered water mark while one of the examiners of DB group was measuring the upper left premolar segment during arch length calculations



**Fig.9.**Showing Exocad 3D CAD software program while one of the examiners of DB group was measuring the mesiodistal widths of the incisors, Canines, and premolars of the lower arch



**Fig.10.**Showing Exocad 3D CAD software program while one of the examiners of DB group was measuring the mesiodistal widths of the incisors, Canines, and premolars of the upper arch



**Results**

The present study was accomplished to evaluate the effect of disregarding and regarding the measurement's errors during TSALD analysis via using the physical and digital tools. So, studying the statistical difference of the measurement errors on the Single-Blinded group and/or Control-Base group on both arches were so important to know the effect of gross, random and systematic errors in this study. The collected data were summarized using mean, standard deviations, median, and range of TSALD measurements of the

maxillary arch (MAX) and mandibular arch (MAN) on DB and CB groups (Table, I). Wilcoxon signed-rank test was used to assess a paired difference test (P Value) of the same 10 examiners on the same maxillary and mandibular 3D printed model and/or 3D surface solid CAD model. The P value of TSALD of maxillary and mandibular arches via digital caliper were statistically insignificant in DB and CB group. Paired difference test of TSALD of upper and lower arches via mimic 3D software were irrelevant significance in both groups.

**Table I.** Comparison of TSALD measurements of MAX and MAN arches via digital caliper and software on DB and CB and the P value presenting negligible statistical difference between both groups:

TSALD Measurements	Descriptive Values	DB group	CB group	P value
		Examiners=10	Examiners=10	
MAX -Digital Caliper	Range	(-10.3 : -1.2)	(-4.7 : -3.9)	0.169
	Mean ± SD	-5.6±2.8	-4.2±0.2	
	Median	-4.8	-4.2	
MAN -Digital Caliper	Range	(-10.1 : -0.9)	(-6.9 : -6.2)	0.445
	Mean ± SD	-7.0±2.8	-6.6±0.3	
	Median	-7.9	-6.6	
MAX - Digital Software	Range	(-7.0 : 4.5)	(-4.7 : -3.7)	0.285
	Mean ± SD	-4.5±3.5	-4.2±0.3	
	Median	-5.6	-4.2	
MAN - Digital Software	Range	(-8.3 : -2.9)	(-6.9 : -5.9)	0.445
	Mean ± SD	-5.8±1.8	-6.4±0.3	
	Median	-6.2	-6.4	

- Wilcoxon signed rank test
- \*: Significant level at P value < 0.05

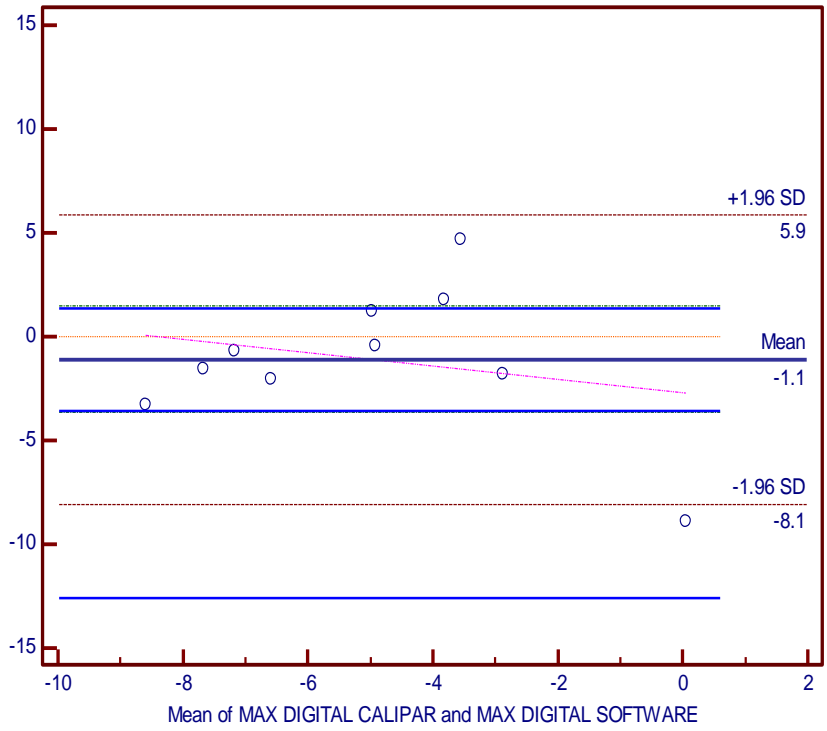
Limits of agreement calculate the range that a part of measurement differences fall. The limits of agreement, which take systematic (bias-mean difference) and random error (precision-upper and lower limits) into account, providing easy way to assess how much a given result will probably vary when obtained using different techniques. The paired t test of the MAX and MAN measurements

via digital caliper and digital software in Double-blinded group showed insignificant difference (Table.2). The three lines in (Graph. 1&2) represent mean of differences -called bias and rest two lines are limits of agreement mean +1.96 SD and mean -1.96 SD. Most of the points in (Graph,1&2) were lying between the limits indicating that there is high level of agreement between the tests.

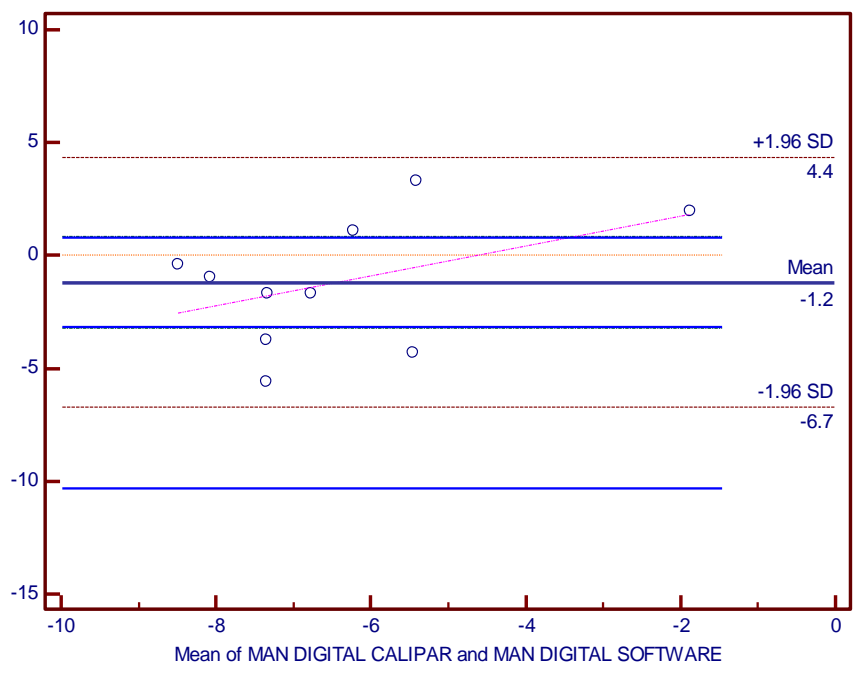
**Table 2.** Mean Difference, Bland-Altman Upper and Lower Limits of Agreements, and 95% CI of Differences Between digital caliper and digital software measurements (Double-Blinded group)

DB Group	Bland-Altman Plot			Pearson's correlation		Paired Samples T test			
	Limits of agreement		P value (linear regression)	r	P value	Mean difference	Mean difference 95% CI		P value
	Lower	Upper					Lower	Upper	
MAX Arch	-8.1	5.9	0.520	0.370	0.293	-1.10	-3.65	1.45	0.356
MAN Arch	-6.7	4.4	0.197	0.314	0.367	-1.19	-3.22	0.83	0.215





**Graph1.**Bland–Altman plot with lines of agreement for maxillary arch measurements in Double-Blinded group



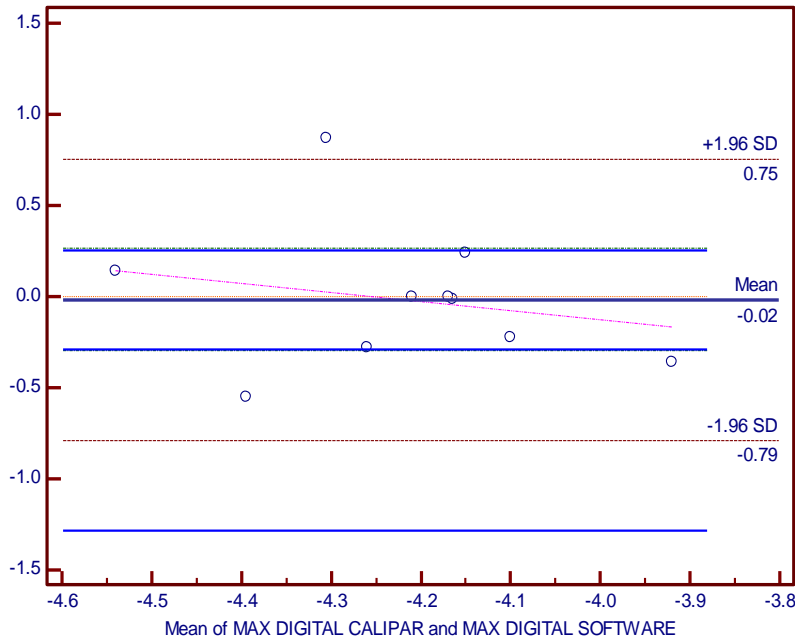
**Graph2.**Bland–Altman plot with lines of agreement for mandibular arch measurements in Double-Blinded group

The paired t test of the MAX and MAN measurements via digital caliper and digital software in Control-Base group showed insignificant difference (Table.3). The three lines in (Graph. 3&4) represent mean of differences - called bias and rest two lines are limits of agreement mean +1.96 SD and mean -1.96 SD. Most of the points in (Graph,1&2) were lying between the limits indicating that there is high level of agreement between the tests.

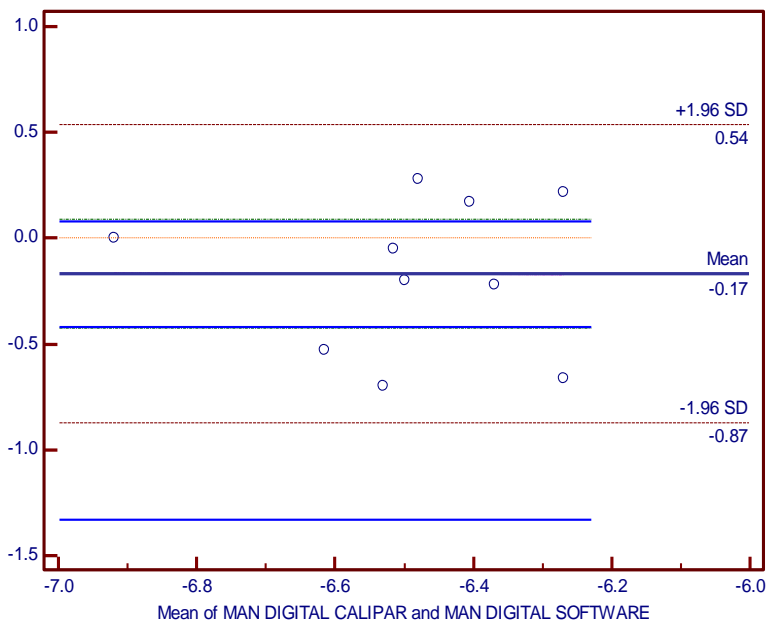


**Table3.** Mean Difference, Bland-Altman Upper and Lower Limits of Agreements, and 95% CI of Differences Between digital caliper and digital software (Control-Base group)

Variables	Bland-Altman Plot		P value (linear regression)	Pearson's correlation		Paired Samples T test			
	Limits of agreement			r	P value	Mean difference	Mean difference 95% CI		P value
	Lower	Upper					Lower	Upper	
MAX	-0.79	0.75	0.547	-0.154	0.671	-0.02	-0.30	0.26	0.894
MAN	-0.87	0.54	0.985	0.048	0.895	-0.17	-0.43	0.09	0.172



**Graph3.** Bland-Altman plot with lines of agreement for maxillary arch measurements in Control-Base group



**Graph4.** Bland-Altman plot with lines of agreement for mandibular arch measurements in Control-Base group



## Discussion

The study's objective is to determine whether the results of TSALD analysis are subject to any discernible statistical or practical effects of measurement errors. Because the diagnosis and treatment strategy may be directly or indirectly impacted by the results of the TSALD analysis. In order to evaluate if the results of the TSALD analysis are reliable or not, reproducibility and repeatability of the results are so crucial<sup>(29)</sup>. Because of this, it is absolutely essential to control random errors during the measuring process. In addition, the precision of measurements during the TSALD analysis is affecting the validity of the results directly. So, controlling the systematic error is so critical issue during measurement procedures. Validity should be originated from reliable and reproducible input<sup>(30)</sup>. Last but not least, understanding the different types of measurement errors that might occur during a measurement procedure is a crucial topic to be covered before the measurement process begins in order to know how to prevent the measurement error as much as possible<sup>(31)</sup>.

Abdulraheem and Bondemark 2018 stated that blinded study was masking some important facts about the study until it is over, and the results are being processed<sup>(32)</sup>. Any information about the measurement mistakes that might occur when reading, recording, and collecting the measurements was kept secret in our study scenario. Additionally, they were unaware that they had been included in the study. The 10 examiners in the beginning of study served as Double blinded examiners (DB group) while they were measuring the TSALD for upper and lower arches of the 3D printed model and calculating it also via 3D Mimic software program. The exclusion criteria were crucial in order to reduce any dental flaws that would have affected the mesiodistal breadth of the teeth<sup>(33)</sup>. The examiners were used electronic caliper to measure the mesiodistal widths of the teeth and segmented arch length of both models. Zilberman, Huggare, and Parikakis 2003 discovered that using digital calipers as a measuring tool led to the most precise and repeatable (reproducible) findings<sup>(34)</sup>. In addition, Harsh and Jain 2022 concluded that the 3D Exocad software was reliable and accurate<sup>(35)</sup>. The six-segment arch length technique, first described by Vego in 1962, was used to measure the arch length of upper and lower arch of the 3D printed model<sup>(36)</sup>. The segmented

arch technique is recognized as a highly simple, accurate, and useful procedure for determining the perimeter of the dental arch<sup>(37)</sup>. After receiving the measurement records from the examiners of DB group, the researcher informed that they were part of a study. In addition, knowing in detail all subjects related to measurement errors, validity, and Reliability. From this turning point, they became spontaneously the examiners of the control-Base group (CB).

On the other hand, the measurement procedures done by the examiners of CB group were totally different in controlling and avoiding all types of measurement errors as possible. However, highly calibrated and accurate measuring tool as digital caliper and software will lead to the accuracy of measure and reduction of systematic (observational and environmental) errors. At the end, it will result in highly valid measurement values as reported by Cacioppo 1982<sup>(38)</sup>. Avoidance of systematic error was done also by careful design of the sample and the study method (sample size and Characterization of the examiners, STL file and 3D printed model of the upper and lower arch), collection forms (copy of illustrated tables), thoroughly documenting the study's methods, testing the data collection instruments, properly training and supervising data collectors, and documenting and computing the data variables as they stated by Emily white and Armstrong 2008<sup>(27)</sup>.

The statistical analysis was summed up using mean, standard deviations, median, and range of TSALD measurements of the maxillary arch (MAX) and mandibular arch (MAN) on DB and CB groups. Wilcoxon signed-rank test was used to assess a paired difference test (P Value) of the same 10 examiners on the same maxillary and mandibular 3D printed model and/or 3D surface solid CAD model. The P value of TSALD of maxillary and mandibular arches via digital caliper were 0.169 and 0.445 respectively which indicated that the statistical differences were insignificant in DB and CB group. Additionally, Irrelevant paired difference data for the P value of the TSALD of MAX and MAN arches via digital software were 0.285 and 0.445 subsequently. Despite the presence of measurement errors environment in Double-Blinded group and devaluation of measurement errors in Control-Base group, the results showed that the direct effect of the measurement errors in this investigation was not detectable statistically. However, the presence of highly precise calibrated



measuring tools, elimination of any extraneous factors (Bias) <sup>(39)</sup> and experienced examiners in TSALD examiners (procedure techniques) in both groups from the start might have an upper hand over the measurement errors.

The quantification of the agreement between two quantitative measurements in both groups (Digital caliper and 3D Mimics software) by studying the mean difference and constructing limits of agreement was done by Bland-Altman analysis<sup>(40)</sup> via using MedCalc statistical software program (MedCalc Software Ltd, Acaciaaan 22, 8400 Ostend, Belgium). The plot graphs of both measuring tools in both groups showing 95% of the data points lying within  $\pm 1.96$  SD of the mean difference. It is possible to say that the bias and the limits of agreement were insignificant, because the line of equality was within the confidence interval of the mean difference<sup>(41)</sup>. The 95% Confidence Interval of agreement limits were showing that the size of the possible sampling error in both measurement techniques for MAX and MAN arches in both groups were insignificant statistically. The paired sample t test mean differences of MAX and MAN arches between both measuring tools in Double-blinded group were 0.356 and 0.215 subsequently and the P value mean differences of MAX and MAN arches between measuring tools in Control-Base group were 0.894 and 0.172 respectively. The insignificant values of the means differences between maxillary and mandibular arches data within the two digital measuring tools in both groups were indicating that there were no detectable measurement errors or bias, or sample error happened.

## Conclusion

The present study concluded that the direct impact of the measurement mistakes in this experiment was not statistically apparent, despite the environment of measurement errors being present in the Double-Blinded group and the devaluation of measurement errors in the Control-Base group. However, the use of extremely accurate calibrated measuring instruments, the removal of any irrelevant variables (Bias) and skilled TSALD examiners (procedural approaches) in both groups from the beginning may have an advantage over measurement mistakes.