A COMPARATIVE EVALUATION OF THE ACCURACY OF DENTAL MODELS PRINTED USING TWO DIFFERENT TYPES OF 3D PRINTING TECHNOLOGIES USING A DIGITAL INSPECTION SOFTWARE- An *In vitro study*

Dr Rahul Ravi[1], Dr Gaurang Mistry[2], Dr Omkar Shetty[3], Dr Kunal Mehta[4], Dr Sheetal Parab[5]

[1]Post Graduate Student, Dept of Prosthodontics,
[2]Professor and Head, Dept of Prosthodontics,
[3]Professor, Dept of Prosthodontics,
[4]Associate Professor, Dept of Prosthodontics,
[5]Associate Professor, Dept of Prosthodontics,
School of Dentistry,
D Y Patil Deemed to be University.

ABSTRACT

3D printing or additive manufacturing has been spreading and advancing rapidly over the past few years. The implications of 3D printing are vast and the technology has the potential to revolutionize and disrupt the world of dentistry, with an ever-increasing application in the field. This study has been conducted to compare the accuracy of dental models 3D printed using two different technologies, namely SLA and DLP 3D printers. Materials and method: A mandibular typodont model was scanned using a professional structured-light desktop scanner to produce a reference 3D model. The STL files of the scanned reference model obtained were exported to both scanners. 3 models were obtained from each scanner and grouped into Group I and Group II. The printed models were then scanned using the desktop scanner to obtain STL files. These STL files were loaded into the 3D evaluation software and individually compared to the reference scan and evaluated in terms of trueness and precision. Results: No significant statistical differences were found in terms of accuracy and precision between Group I and Group II

Keywords: 3D Printing, DLP, SLA, CAD-CAM, Accuracy, Trueness, Precision

Introduction:

Digital is the new trend Over the past several decades there have been countless technological innovations that have had a major impact on the world. Arguably, one of the most monumental has been the invention of the 3D printer by Charles Hull, a device that can create real, tangible 3D objects in real-time based on the details from a digital design.

Virtual dental casts have contributed to the efficiency of the dental laboratory process. Digitalized casts have the significant advantages of efficiency, convenience, durability, and space efficiency. However, digitalized casts need to be converted into actual casts for diagnosis or to fabricate appliances. Three-dimensional manufacturing is a method of producing actual casts from digital data[5, 6] . When a physical model is fabricated using the CAD/CAM system, a number of steps can be omitted from the process for the fabrication of digital models. This results in lead time being shortened and multiple copies which are free from distortion can be obtained as a result of having exact 3D digital data. Therefore, digital models are recommended as an alternative to conventional plaster models.

Azari et al have discussed the most frequent rapid additive prototyping technologies that have been adopted in dentistry.[7,8,9] They are:

1. Fused Deposition Modelling (FDM)

2. Stereolithography (SLA)
3. Inkjet-based system (DLP)
4. Selective laser sintering (SLS)

The term 3D printing is generally used to describe a manufacturing approach that builds objects one layer at a time, adding multiple layers to form an object.[9, 10]

This study has been conducted to compare the accuracy of dental models 3D printed using two different technologies. ‘Precision’ and ‘Trueness’ are terms that represent different measures of accuracy. The outcome of such a study could have an impact on the preferred method of model fabrication especially with respect to efficiency.

Materials and method:

The materials and equipment used for this study are as follows :

1. Basic materials/armamentarium used for the study
2. Equipment used for 3D printing of the dental models
3. Software to evaluate the trueness and precision of the 3D printed models

1. BASIC MATERIALS /ARMAMENTARIUM USED FOR THE STUDY

i. Mandibular Hard Gingiva Typhodont Model [PRO2001-UL-SC-FEM-32] (Nissin Dental Products Inc, Minami-ku, Kyoto, Japan) ii. HP Spectre x360 Laptop (Hewlett-Packard, Palo Alto, California; 8th Gen, Core i7) iii. Shining AutoScan DS-EX Desktop Scanner (Shining 3D, Hangzhou, China) iv. Easy Scan Spray (Alphadent, Gyeonggi-Do, Korea)

2. EQUIPMENT AND MATERIALS USED FOR 3D PRINTING OF THE DENTAL MODELS

i. SLA Printer (Form 2, 3D Systems, Formlabs, Massachusetts, USA) ii. DLP Printer (Anycubic Photon, Anycubic, Shenzhen, China) iii. 3D Cast Resin (Senertek, Izmir, Turkey)

3. SOFTWARE TO EVALUATE THE ACCURACY (TRUENESS AND PRECISION) OF THE 3D PRINTED MODELS

i. Geomagic Control X (3D Systems, 2018, Morrisville, NC, USA)

Geomagic® Control X™ is a professional 3D quality control and dimensional inspection software that lets one capture and process the data from 3D scanners and other portable devices to measure, understand and communicate inspection results to ensure quality everywhere, allowing for repeatable inspection routines, analysis of size, shape, and location of deviation groups, providing statistical data and a graphical representation about the same. The version of the software used was 2018.1.0.2341.

The methodology of this study was divided into the following steps:

1. PREPARATION OF THE TYPHODONT MODEL

A mandibular typhodont model (Nissin) was used as the reference model for this study. The model was evenly sprayed with two coats of the Easy Scan spray (Alphadent), in order to create a non-reflective, matte surface. The model was allowed to dry for about 30 seconds before proceeding with the scanning.

2. SCANNING OF THE TYPHODONT MODEL

The desktop scanner (Shining 3D AutoScan DS-EX) was used for scanning the mandibular typhodont model (Reference model), ensuring ambient lighting conditions in the scanning room environment. The desired model scan which was used as a reference to 3D prints the models was exported in an STL file format to CAM software for 3D printing.

3. PRINTING THE MODELS USING 3D PRINTERS

The STL files of the scanned Reference model were exported to both the printers (SLA and DLP). The 3D model samples to be printed were divided into 2 groups depending on the printer used.

Group I – 3 models printed using the SLA printer (Formlabs Form 2). They were further categorised as Group I (A, B, and C).

Group II – 3 models printed using the DLP printer (Anycubic Photon). They were further categorised as Group II (A, B, and C).

These two groups of 3D printed models (Group I and Group II) were then again prepared for scanning using the desktop scanner (Shining AutoScan DS-EX). The models were first evenly coated with two layers of the Easy Scan spray, allowed to air dry, and then individually scanned by placing them on the model fixture attachment. The scans were inspected for any imperfections.

EVALUATION OF THE SCANNED 3D MODELS

Each scan was individually loaded into the 3D evaluation software (Geomagic Control X, 2018, Morrisville, NC, USA) and all areas not relevant for evaluation were removed. On the reference scan model, forty points were marked on the occlusal cusp tips of the posterior teeth and on the incisal edges of the anterior. Sixteen points each were also marked on the buccal and lingual cervical aspects of each tooth. These exact same points were also marked for all Group I and Group II models by the software and the gap distances (deviations) at these points would then be evaluated and measured using the software.

RESULTS:

Table 1: Descriptive statistics of Gap distances (mm) in different Group I sample (SLA)

Table 2 : Descriptive statistics of Gap distances (mm) in different Group II samples (DLP)

Table 3 : Comparison of Gap distances (mm) for evaluation of Trueness between Group I (SLA) and Group II (DLP) samples

Table 4 : Comparison of Gap distances (mm) for evaluation of Precision between different Group I (SLA) and Group II (DLP) samples using ANOVA

Table 5 : Pairwise multiple comparisons of Precision in different Group I (SLA) and Group II (DLP) samples using ANOVA and Post-Hoc Tukey test

Table 6 : Descriptive Statistics of Gap distances (mm) for evaluation of Linear Dimension Deviation in Group I samples

Table 7 : Descriptive Statistics of Gap distances (mm) for evaluation of Linear Dimension Deviation in Group II samples

Table 8 : Comparison of Trueness of overall linear dimension deviation (mm) between Group I (SLA) and Group II (DLP) samples

Table 9 : Comparison of Trueness of Linear dimension deviation (mm) for 2^{nd} Molar, 2^{nd} Premolar and Canine between Group (SLA) and Group II (DLP) samples

The results showed a statistically insignificant difference between Group I and Group II, although Group II showed slightly better trueness and precision values.

Discussion:

Different types of 3D printers are available today. Studies evaluating the 3D accuracy of dental models and specifically complete-arch 3D printed models are limited. Hence, there is a need to evaluate the clinical validity of different 3D printers, printing materials and cast quality. SLA and DLP technologies are the most commonly used 3D printing technologies in dentistry in terms of printing accuracy, quality, speed, cost, and the possibility of printer miniaturization.[16] Therefore, SLA and DLP are the 3D printing methods used in this study.

Till date, the accuracy of dental models has been primarily evaluated by linear distance measurements. This method is insufficient due to the lack of measuring points and the inability to measure repeatable measuring points.[14,16] Recently, 3D analysis software is being used to analyze model deviations. Artificial errors in manual measurements are largely avoided because the alignment, superimposition, and 3D comparisons are performed by the computer. The analysis completely depicts the deviations of all points in 3D space, allowing for a more in-depth and stable evaluation. Also, the deviation range and area of the model can be confirmed through the colour difference map. Past studies have shown that 3D analysis is more reliable and valid than conventional measurements. Therefore, this study has used 3D volumetric analysis to evaluate the accuracy of the models.

The reference model was then scanned using the desktop scanner (Shining AutoScan DSEX) in ambient lighting conditions to ensure proper detail was being recorded and it was stored as an STL file.[20,21] The STL files were then exported to the SLA and DLP printers and three models each were printed, categorized as Group I (SLA) and Group II (DLP). In this study, for the purpose of maintaining uniformity and for better accuracy for both groups, a z-axis layer height of 25μm was chosen, even though these printers are capable of printing with layer heights ranging from 25-100 μm.[22] Both groups of models were printed such that the occlusal plane of the 3D models was parallel to the platform to reduce printing errors.[23] Though the SLA and DLP printers used in this study (FormLabs Form 2 and Anycubic Photon) recommend the use of proprietary resins, both sets of models in this study were printed using the SNR Cast Resin as it is compatible with both SLA and DLP printers and for the sake of uniformity in the properties of the resin.

Once scanned, the model files were loaded onto the RE software. Forty points were marked on the occlusal cusp tips of the posterior teeth and on the incisal edges of the anteriors of the reference scanned model. Sixteen points were also marked on the buccal and lingual cervical aspect of each tooth on the same models. The exact coordinates were exported to each of the other scans of Group I and Group II and the gap distances were measured. The models were then evaluated in terms of trueness and precision. Once all the measurements were made, the results were tabulated and evaluated for trueness and precision.

Table 1 shows the minimum and maximum gap distances in mm between each of the different scan samples of Group I and the reference scan. It also shows the mean gap distance in mm and the standard deviation between each Group I sample and the reference scan.

Table 2 shows the minimum and maximum gap distances in mm between each of the different scan samples of Group II and the reference scan. It also shows the mean gap distance in mm and the standard deviation between each Group II sample and the reference scan.

Table 4 shows the comparison of Precision of gap distances in different Group I and Group II samples. The p-value for each group was obtained using the One-way ANOVA test. The pvalue obtained for Group I and Group II was 0.187 and 0.985 respectively. As the p-value was greater than 0.05, the result was considered statistically insignificant.

Table 5 shows of pairwise multiple comparisons of precision within Group I and Group II samples and the p-value obtained using the Post-Hoc Tukey Test. The p-value in all instances was always greater than 0.05, thus accepting the null hypothesis. Since no statistically significant difference was found previously using the ANOVA test, the Post-Hoc Tukey test was expected to show an insignificant difference. This once again could be justified due to the same resin, print layer height and post-curing conditions being used. According to the study conducted by Kim SY and co-authors,[28] DLP technique is faster and uses a projector to cure the material layer by layer which reduces the error associated with repeated printing, explaining why Group II was seemingly more precise in duplicating models' multiple number of times though it was statistically significant. The Precision typically depends on the practitioner's ability to maintain the stability of the scanner wand[22]; however, this study uses a fixed desktop scanner, where the distance was maintained at a constant value. Therefore, the precision of this study could be considered higher than previous studies, where this distance was variable. The print angulation and slice angles affect the accuracy of SLA printed dental models. Alharbi et al.[13]found out that a 120° slice angle resulted in the highest accuracy of printed models, which could have influenced the accuracy of Group I models.

Tables 6 and 7 show the reference values of linear inter-2nd molar, inter-2nd premolar and inter-canine distances; the measured values for each of the samples within Group I and Group II and the deviation of each measured value from the reference value.

Table 8 shows the overall comparison of Trueness in linear dimension deviation between Group I and Group II samples. The p-value of 0.23 was considered to be statistically insignificant.

Table 9 shows comparison of trueness of linear dimension deviation for the 2nd molar, 2nd premolar and canine between Group I and Group II samples.
Discrepancies of reference points could have developed during the procedure of fabrication of the models. Therefore, in this study the Best Fit alignment method was used in addition to having fixed reference points to minimize the errors produced in analyzing and comparing the dental models.[6]

References

1. Choi JW, Ahn JJ, Son K, Huh JB. Three-Dimensional Evaluation on Accuracy of Conventional and Milled Gypsum Models and 3D Printed Photopolymer Models. Materials (Basel). 2019; 12(21):3499.
2. Dawood A, Marti B; Sauret-Jackson, V, Darwood A. 3D printing in dentistry. BritDentJ. 2015; 219(11), 521–9.
3. Sason GK, Mistry G, Tabassum R, Shetty O. A comparative evaluation of intraoral and extraoral digital impressions: An *in vivo* study. J Indian Prosthodont Soc. 2018; 18(2):10816.
4. Park ME, Shin SY. Three-dimensional comparative study on the accuracy and reproducibility of dental casts fabricated by 3D printers. J Prosthet Dent. 2018; 119(5):861.e1-e7.
5. Kim WT. Accuracy of dental models fabricated by CAD/CAM milling method and 3D printing method. J Oral Res. 2018; 7(4):127-133.
6. Azari A, Nikzad S. The evolution of rapid prototyping in dentistry: A review. Rapid Prototyping Journal. 2009; 15(3):216-25.
7. Torabi K, Farjood E, Hamedani S. Rapid Prototyping Technologies and their Applications in Prosthodontics, a Review of Literature. J Dent (Shiraz). 2015; 16(1):1-9.
8. Kohli T. 3D Printing in Dentistry – An Overview. Acta Scientific Dental Sciences. 2019; 3(6):35-8.
9. Arakida T, Kanazawa M, Iwaki M, Suzuki T, Minakuchi S. Evaluating the influence of ambient light on scanning trueness, precision, and time of intra oral scanner. J Prosthodont Res. 2018;62(3):324-9
10. Zhang ZC, Li PL, Chu FT, Shen G. Influence of the three-dimensional printing technique and printing layer thickness on model accuracy. J Orofac Orthop. 2019;80(4):194-204.
11. Favero CS, English JD, Cozad BE, Wirthlin JO, Short MM, Kasper FK. Effect of print layer height and printer type on the accuracy of 3-dimensional printed orthodontic models. Am J Orthod Dentofacial Orthop. 2017;152(4):557-65.
12. Watters MP, Bernhardt ML. Curing parameters to improve the mechanical properties of stereolithographic printed specimens. Rapid Prototyping Journal. 2018; 24(1):46-51.

13. Jindal P, Juneja M, Bajaj D, Siena FL, Breedon P. Effects of post-curing conditions on mechanical properties of 3D printed clear dental aligners. Rapid Prototyping Journal. 2020; 26(8):1337-44.
14. Wang W, Yu H, Liu Y, Jiang X, Gao B. Trueness analysis of zirconia crowns fabricated with 3-dimensional printing. J Prosthet Dent. 2019;121(2):285-91.
15. Gjelvold B, Mahmood DJH, Wennerberg A. Accuracy of surgical guides from 2 different desktop 3D printers for computed tomography-guided surgery. J Prosthet Dent. 2019; 121(3):498-503.

sin)

Fig. 3 : Desktop scanner (Shining AutoScan DS-EX)

Fig. 5(a),(b) : SLA Pri

ISSN 2515-8260 Volume 05, Issue 1, 2018

Fig. 6(a),(b) : DLP Printer (Anycubic Photon)

Fig. 7 : 3D Printing Resin (SNR Cast Resin)

Fig. 9 : Reference model being scanned

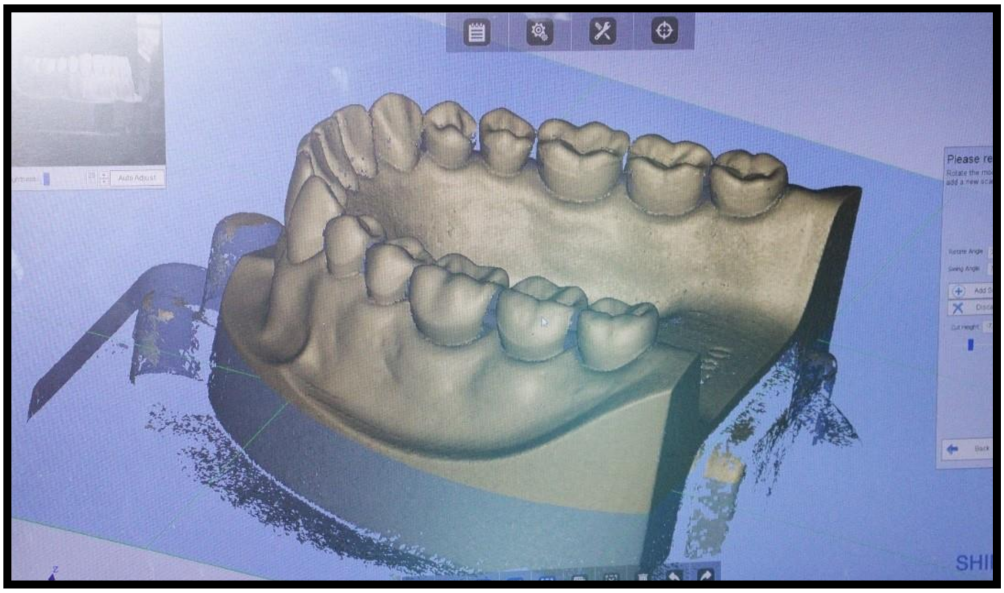


Fig. 11 : The built-in model builder platform

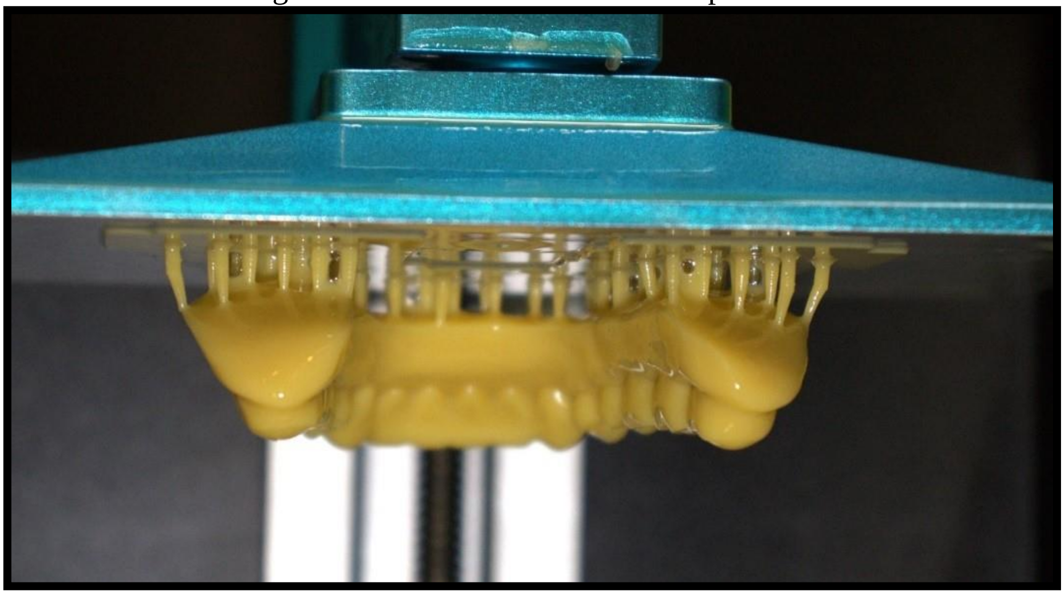


Fig. 14 : Group II (DLP) model being printed

Fig. 16: 3D printed model placed in an ultrasonic bath

Fig. 19 (a), (b) : 3D printed model being scanned using the desktop scanner

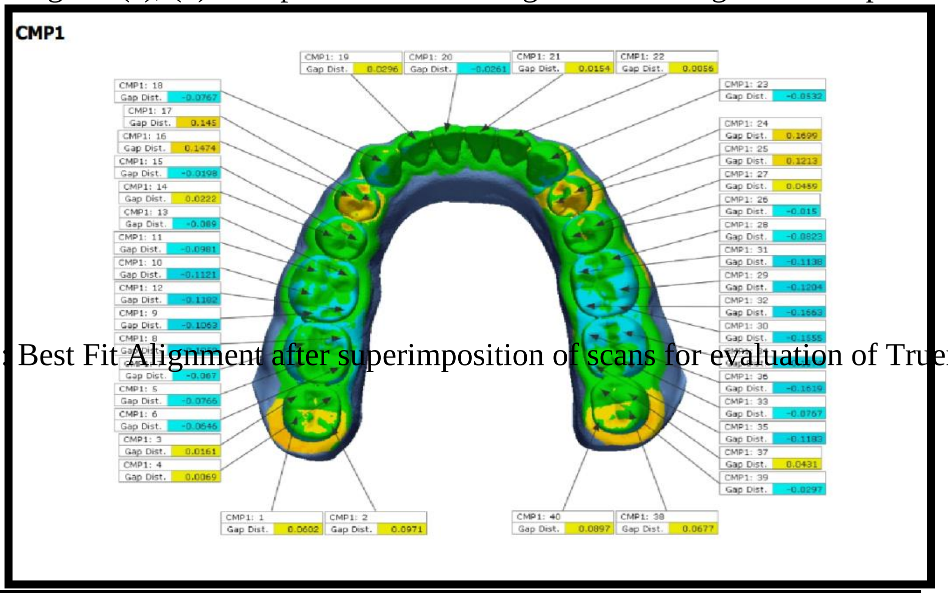


Fig. 21 : Best Fit Alignment after superimposition of scans for evaluation of Trueness

\

\

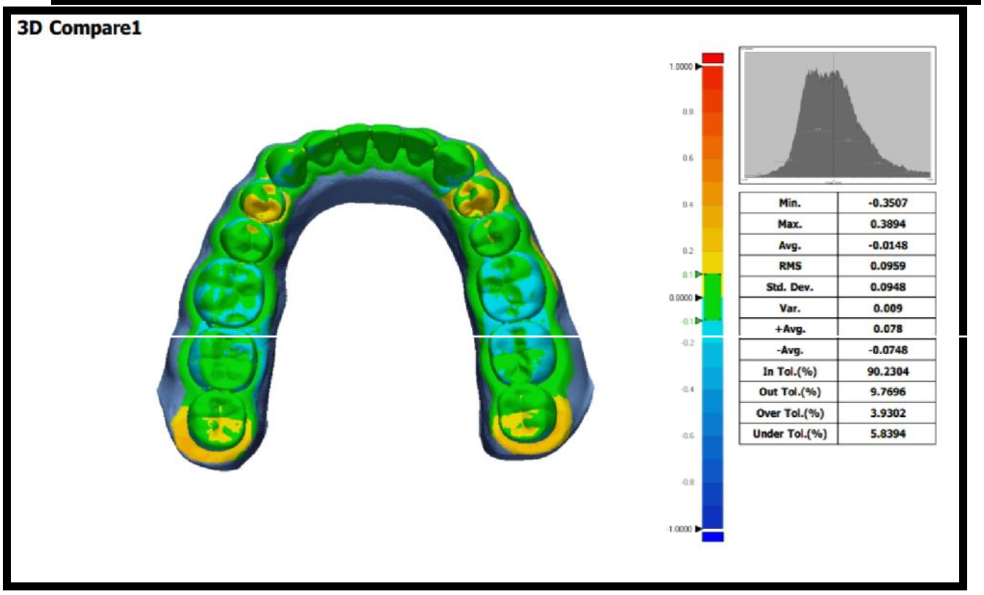


Table 1 - Descriptive statistics of Gap distance (mm) in Group I samples (SLA)

ISSN 2515-8260 Volume 05, Issue 1, 2018

	Minimum	Maximum	Mean	Std. Error	Std. Deviation
Group I A	-0.20	0.16	-0.04	0.00	0.08
Group I B	-0.19	0.17	-0.03	0.01	0.10
Group I C	-0.47	0.19	-0.06	0.01	0.10

Table 2 - Descriptive statistics of Gap distance (mm) in Group II samples (DLP)

	Minimum	Maximum	Mean	Std. Error	Std. Deviation
Group II A	-0.31	0.45	-0.03	0.01	0.14
Group II B	-0.41	0.64	-0.03	0.02	0.18
Group II C	-0.45	0.67	-0.02	0.02	0.21

Table 3 - Comparison of Trueness of Gap distance (mm) between Group I and Group II samples

		Mean	Std. Deviation	Std. Error Mean	Mean difference	t	p-value
Overall Gap	Group I	-0.048591	0.1002694	0.0068225	-0.01	-1.568	0.118

distance (mm)	Group II	-0.030420	0.1840985	0.0125263			

*p-value < 0.05 statistically significant

Table 4 - Comparison of Precision of Gap distance (mm) in different Group I and Group II samples (ANOVA)

		Sum of Squares	df	Mean Square	F	p value
Gap distance (mm) - GROUP I	Between Groups	0.034	2	0.017	1.692	0.187
Gap distance (mm) - GROUP II	Between Groups	0.001	2	0.001	0.015	0.985

*p-value < 0.05 statistically significant

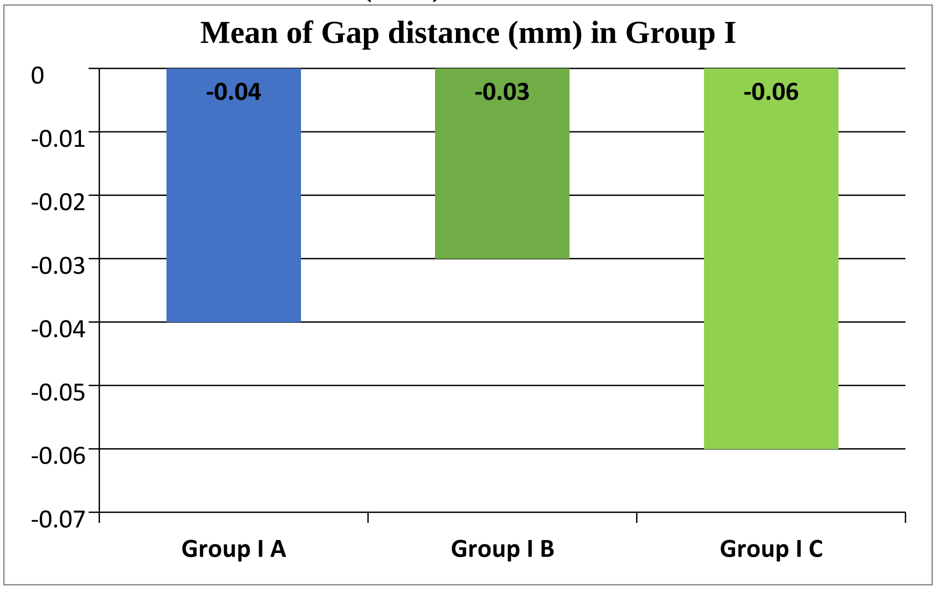
Table 8 - Comparison of Trueness of overall linear dimension deviation (mm) between Group I and Group II samples

	Minimum	Maximum	Mean	Std. Error	Std. Deviation	Mean difference	t	p-value
Linear dimension deviation GROUP I	-0.05	0.04	-0.01	0.01	0.03	-0.01	-1.27	0.23
(mm)								

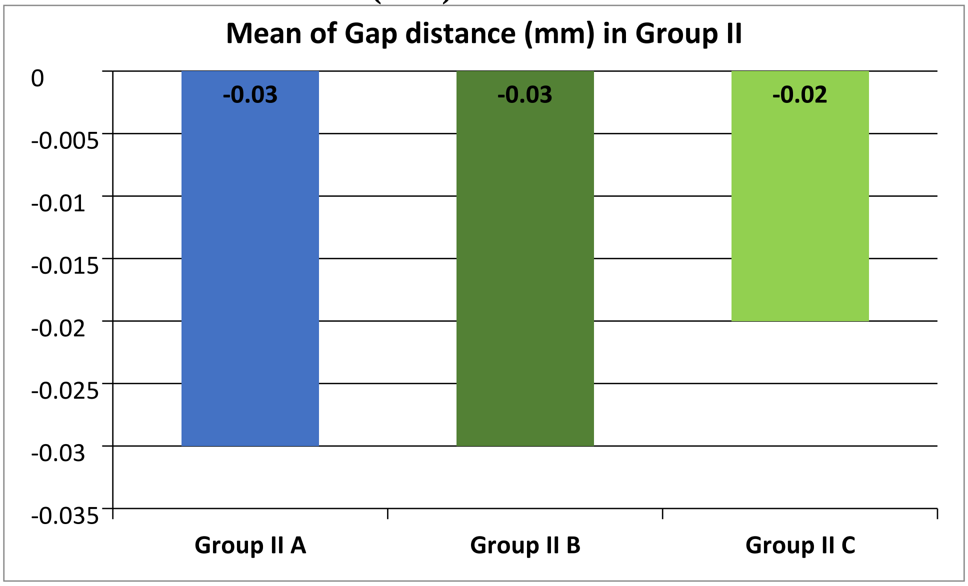
Linear dimension n deviation GROUP II (mm)	-0.03	0.02	0.00	0.00	0.02			

*p-value < 0.05 statistically significant

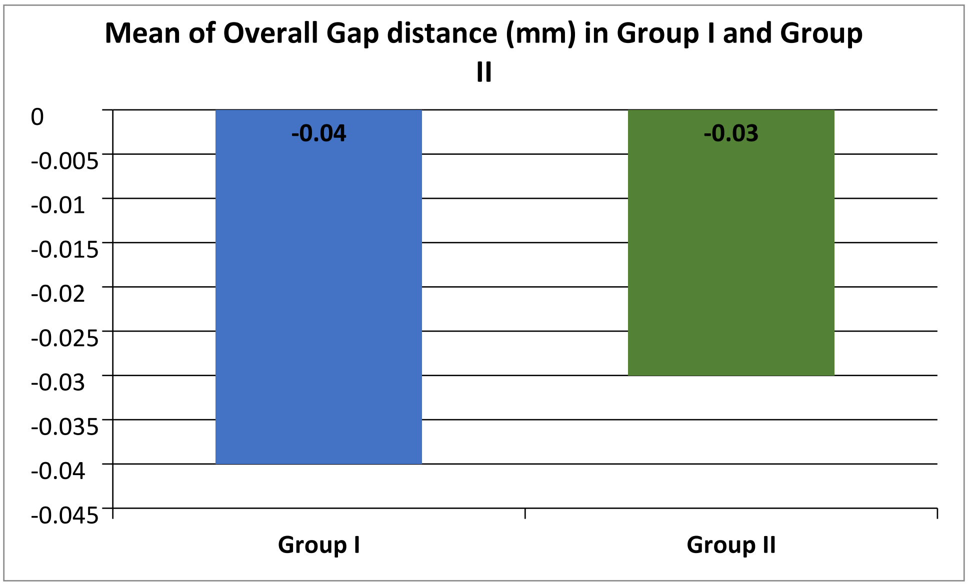
GRAPH 1
MEAN OF GAP DISTANCE (MM) IN DIFFERENT GROUP I SAMPLES



GRAPH 2
MEAN OF GAP DISTANCE (MM) IN DIFFERENT GROUP II SAMPLES



GRAPH 3
MEAN OF OVERALL GAP DISTANCE (MM) IN GROUP I AND GROUP II SAMPLES



GRAPH 4
MEAN OF LINEAR DIMENSION DEVIATION (MM) OF GROUP I AND GROUP II SAMPLES