"CONVENTIONAL IMPRESSION VERSUS EXTRAORAL AND INTRAORAL SCANS - A COMPARATIVE IN-VITRO EVALUATION"

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MASTERS IN DENTAL SURGERY

In

PROSTHODONTICS AND CROWN & BRIDGE

By

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Under the guidance of

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I hereby declare that this dessertation entitled **"CONVENTIONAL IMPRESSION VERSUS EXTRAORAL AND INTRAORAL SCANS- A COMPARATIVE IN-VITRO EVALUATION"** is a bonafide and genuine research work carried out by me under the guidance of **Prof. (Dr.) Swati Gupta**, ***Professor and Head*** , Department of Prosthodontics and Crown & Bridge, Babu Banarasi Das College of Dental Sciences, Babu Banarasi Das University, Lucknow, Uttar Pradesh.

Date: 14 Feb'2023

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Dedicated to

My Teachers, Family

&

Friends

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Dr. Akanksha

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LIST OF ABBREVIATIONS

Abbreviation	Full form
3D	3 Dimensional
CAD-CAM	Computer-Aided Design and Computer-Aided Manufacturing
IOS	Intraoral Scanner
EOS	Extraoral Scanner
CEREC	Chairside Economical Restoration of Esthetic Ceramics
RM	Reference Model
DD	Direct Digitalization
PDD	Partially Direct Digitalization
ID	Indirect Digitalization
PVS	Polyvinylsiloxane
. STL	Standard Tessellation Language / Standard Triangle Language
BL	Bucco-lingual
MD	Mesio-distal
MP	Mesio-proximal
DP	Disto-proximal
SD	Standard Deviation

Abstract

STATEMENT OF PROBLEM: There is still "in progress search" for evidence to assess the accuracy of several digital impressioning , such as intraoral scanning, impression scanning, and cast scanning, for the fabrication of single tooth supported restorations.

PURPOSE : The purpose of this in vitro study was to determine the accuracy of conventional impression with that of digital impressions for single tooth supported crowns so as to predict internal and proximal fit

MATERIALS AND METHODS: A typodont acrylic resin right mandibular first molar was prepared for an all-ceramic crown, and a round diamond point bur was used to form indentations. Reference datasets were produced by measuring the inner edges of indentations using digital vernier calliper. There are three methods to utilize digital impressioning systems namely- Direct, Partially Direct, and Indirect digitalization, therefore 20 scans of these three groups were made and acquired datasets were measured in a similar manner as for reference dataset but with software built calibrated measurement tool. Repeated scans were checked for precision in each group and the groups were compared with reference value to assess the trueness.

RESULT : The precision variances for IOS was 23μm followed by 32 μm for impression scans and 36 μm for cast scans. Scans achieved by IOS exhibited highest trueness with SD ranging from 42 μm-55 μm, whereas scans achieve by extraoral scanner had deviation ranging from 57 μm-105 μm.

CONCLUSION: Precision and trueness were superior for IOS scans than extraoral scans. Although, both the scanner provides a clinical acceptable dimensional misfit prosthesis as the misfit value should be <150 μm.

KEYWORDS

Digital impressions, Precision, Trueness, Intraoral scanners, Desktop scanners, Digital impression techniques, Conventional impression

Introduction

With the advent of digitalization, dentistry in general has taken a huge leap in terms of accuracy, efficiency, time management , productivity, and predictability. In the field of prosthodontics , impressions form the foundation of any procedure. Dental impressions, whether traditional or digital, are primarily used to obtain an imprint among one or more prepared teeth, including neighbouring and antagonist teeth, as well as the interocclusal record relationship[(1)]. The impression's reproducibility is a key factor that represents the final outcome of the expected restoration.

Different impression material and techniques have been proposed to achieve highly accurate conventional impression. The accuracy of these conventional impression is investigated by several in vitro studies which evaluated the changes in the linear dimensions between original master cast and gypsum cast obtained after pouring the impressions[(2–6)]. The accuracy is influenced by the impression material used, as well as the impression technique employed, the disinfection process, the transit, the setting time, the type of gypsum used, and even the time between single steps. These issues with traditional impression procedures have highlighted the applicability of intraoral scanners (IOSs) even more. Digital impressions through three-dimensional images provide for the virtual definition of various treatment strategies and thereby digitally designing and fabricating varied types of restorations. From the standpoint of both dentists and patients, intraoral digital scanning has been considered as a more quick and convenient procedure to access the digital workflow of CAD-CAM.

When it comes to digitization in impression production, there are three methods[63-65] for capturing an impression: *direct digitalization, partially direct digitalization and indirect digitalization.* These methods utilise lab scanners , intraoral scanners or a combination of the two. Direct digitalization is a one-step procedure in which impressions are acquired using an optical intraoral scanner, whereas indirect digitalization is a multistep process in which casts are generated from impressions and scanned under a desktop scanner to get positive digital image display. Partially direct digitalization is an intermediate method of digital impression recording in which the negative elastomeric imprint is scanned using a desktop scanner to create a positive digital image of intraoral anatomy.

Extraoral scanners are also known as desktop scanners, 3D scanners, Tabletop scanners, laboratory scanners, and indirect scanners in documentation. These scanners have both advantages and downsides. To begin, there are clinical scenarios where an intraoral scanning equipment cannot be employed, such as highly reflecting surfaces, particularly deep subgingival preparations with difficult tissue management, wetness, and bleeding. Typically, 3D scanners for dental models are provided in conjunction with a software package that allows the dental technician to begin design and production immediately. Other advantages of lab scanners[(7)] are their speed, high number of pixels, which leads to greater accuracy when designing complex restorations, cost effectiveness, improved communication with dental laboratories, and no need of in-office milling unit. But 3D scanners are clogged with certain errors[(8)] and imperfections throughout each stage due to an indirect approach and multistep method, optical intraoral scanning appears to be a reasonable route to digital workflow of CAD/CAM restorations.

Early digital workflows were only partially digital, relying on a desktop scanner, impressions, and the creation of a working model. Direct digitization initially appeared in the 1980s, with CEREC (Sirona Dentistry System GMBH, Blenheim, Germany) being the first intraoral scanner to be sold in the dental market for digital intraoral impressions[(9)]. Workflow using intraoral scanning is quite direct, with fewer intermediary processes, allowing for greater control, fewer failures and has been proven to be highly accurate for single crown quadrant restorations[(10–12)]. Digital intraoral scanning has provided numerous benefits such as real-time visualization, easy repeatability, selective capture of the relevant areas, no need to disinfect and clean dental impressions and trays, pouring of casts, less abrasion of model, ease of communication and accessibility[(13,14)]. Inspite of all the advantages of intraoral scanning, there are various reasons why most dental offices continue to employ the traditional workflow, which includes impression making, gypsum pouring, and indirect digitalization in the dental laboratory. Digital scanning has increased the acceptance by the patient reducing the number of appointments, elimination of flow of impression material and enhanced patients' comfort. But the expensive cost of the equipment, the integration of the new processes into everyday routines, and the reorganisation of the synchronisation between the dental office and dental laboratory are major deterrents for digitization to be widely acceptable. It has also been observed that the adoption of novel intraoral scanning technologies is favoured by the younger generation over the elder age[14–18].

In contrast to ceramic fusions, veneering procedures, or facings, a physical model is not necessarily essential when it comes to monolithic restoration, which is becoming a milestone in restorative dentistry. Eliminating a physical model may save vital time in the manufacturing process while also reducing material costs, resulting in impressions being digitised directly beneath desktop scanners (partial digital workflow). So far, the results are contradictory, with studies preferring impression digitalization over indirect digitalization in terms of clinical indication of short span restorations[19,20] and studies supporting cast scanning over impression scanning [19–21]. As a result, the accuracy of traditional impressions with direct digital, partial digital, and indirect digital impression technologies must be assessed.

When addressing impression accuracy, the phrases "accuracy," "trueness," and "precision" should be understood. The International Standard Organization (ISO) defined "accuracy" in 1994 as a combination of "trueness" and "precision[44]. Accuracy represents an important aspect to compare traditional impressions with digital impressions. When employing scanners, Trueness is the comparison between a reference dataset and a test dataset, whereas Precision is the comparison between several datasets taken from the same object using the same scanner. Accuracy of any scanning system involved in scanning tooth surfaces will ultimately determine the marginal and internal fit of the restoration to the abutment tooth[22–29]

Different scanning methods[30–35] have been applied in different IOSs, which may result in varying scanning accuracies; thus, for best results, it is always suggested to follow the scan sequence according to the manufacturer's instructions or any published scanning strategies.

A uniform consensus on the superiority of either of these impression techniques viz. digital, partially digital, indirect digital and analogue impression is unclear , therefore the study was planned at Post Graduate Department of Prosthodontics and Crown & Bridge, BBD College of Dental Sciences, Lucknow to compare the accuracy of digital and analogue impression.

Aims & Objectives

AIM

- To evaluate and compare the accuracy of conventional impression and digital impression technique for single tooth supported crowns so as to predict internal and proximal fit.

OBJECTIVES

1. Record impression with the intraoral scanner
2. Record impression using polyvinylsiloxane impression material
3. Scan PVS impression with laboratory scanner
4. Scan dental stone cast obtained with PVS impression with laboratory scanner.
5. Compare the scans obtained with - one scan intraoral and two scans -extraoral scanner.
6. Compare the above two with Reference model dataset

HYPOTHESIS

The hypothesis for the above-mentioned aim and objectives were as follows:

1. **Hypothesis 1 (H_1)-** Is there a difference in accuracy between conventional impression techniques and digital impression techniques?

   Null Hypothesis (H_0)- There is no difference in accuracy of conventional impression technique when compared to digital impression techniques

Alternate Hypothesis (H_a)- There is a positive correlation between the accuracy of digital and traditional impression techniques.

2. **Hypothesis 2 (H_2)-** Is there an accuracy difference between intraoral scanning, impression scanning, and cast scanning digital impression techniques ?

Null Hypothesis (H_0)- There is no accuracy difference between intraoral scanning, impression scanning, and cast scanning digital impression techniques

Alternate Hypothesis (H_a)- There is a positive correlation between accuracy of intraoral scanning, impression scanning and cast scanning digital impression techniques

Review of Literature

Franco et al. [36] assessed one-step versus two- step double mix technique and showed that single step impression making technique had lesser discrepancies compared to the 2-step technique

Seelbach et al. [37] conducted a study to compare the accuracy of full ceramic crown obtained from intraoral scans with conventional impression techniques and concluded that digital impression systems allow fabrication of fixed prosthetic restorations with similar accuracy as conventional impression method.

Ender Mehl et al. [38] investigated the accuracy of conventional and digital impression used to obtain full arch impressions. Conventional and digital impressions showed differences regarding full arch accuracy. Digital impressions do not show superior accuracy however they provide excellent clinical results within their indications applying correct scanning technique.

Rhee et al. [39] analysed superimpositions of 3D digital models for comparing conventional impressions and digital impressions and concluded that intra oral scanners lacked fixed references. All subsequent images are stitched to the previous image by best fit algorithm. Hence, the longer the scanning field , the larger the errors.

González de Villaumbrosia et al. [40] concluded that dental preparations must have smooth surfaces without sharp edges or undermined areas for optimal CAD/CAM scanner reading. The resolution of a scanner affected its capacity to read the sharp features of a scanned surface but had no effect on its general trueness or precision. Every extraoral CAD/CAM scanner tested was clinically acceptable in terms of accuracy. The different technologies (light, laser, or contact) do not affect scanners' overall reliability, but specific aspects of the scanning procedure do.

Takeuchi et al. [41] conducted a 7-year literature search and concluded that restorations and fixed dental prostheses made using available digital impression technologies and intraoral scanners had clinically acceptable margins of gap in both direct and indirect procedures.

Sason et al. [31] evaluated and compared the accuracy of intraoral and extraoral digital impression. The intraoral scanner showed higher "precision" and "trueness" values when compared with the extraoral scanner.

Sason et al. [31] used a round diamond point bur to make dimples in the centre of bucco-occlusal, mesio-occlusal, disto-occlusal and linguo-occlusal line angles as reference points to make measurements. A digital vernier calliper was used to measure the distance between the dimples on the reference gypsum cast.

Ranjukta Sar Avhad et al. [41] assessed the accuracy of stone dies poured from polyvinylsiloxane impressions using one-step putty wash and two-step putty wash technique and concluded that the accuracy of two-step impression technique was more than one-step impression technique. Casts were more accurate because of the uniform space provided for the wash impression.

Latham et al. [42] evaluated and compared the effect of scanning patterns on trueness, precision and speed of complete -arch digital scans by using 4 different digital scanning system. Individual scanners' complete-arch scan speed, trueness, and precision differ. The scan pattern can have a significant impact on the success of digital scanning.

Garg et al. [30] evaluated and compared the dimensional accuracy of stone models fabricated by three different impression techniques using 2 brands of polyvinyl siloxane material and concluded that two step impression technique produced more accurate results and out the two brands , Aquasil produced better results.

Diker and Tak [43] evaluated the accuracy of six recently introduced intraoral scanners for single crown preparation and determined the scanning sequence on the accuracy Six different IOSs were used to scan the model ten times each (Trios, iTero, Planmeca Emerald, Cerec Omnicam, Primescan, and Virtuo Vivo). Digital impression accuracy varied depending on the IOS and scanning sequence employed. Highest trueness was obtained from Primescan followed by Trios, Omnicam, Virtuo Vivo, iTreo and least by Emerald. Highest precision was obtained by Primescan followed by Trios, iTreo, Omnicam, Virtuo Vivo and least by Emerald.

Zarone et al. [32] investigated and compared the accuracy of three different scanning techniques. The buccal vestibule was scanned with a longitudinal movement ending on the palatal vault with a posteroanterior direction in the Bucco palatal technique; the S-shaped technique was based on an alternate palatobuccal and Bucco palatal scan along the ridge; the palate was scanned with a circular movement and then with a longitudinal movement along the buccal vestibule in the palatobuccal technique. Bucco palatal method exhibited higher mean trueness and precision values.

Tabesh et al. (44) compared the marginal adaptation of single unit zirconia crowns fabricated with digital scans and conventional impression technique. After compilation of various databases , it was found that the digital scanning prepared teeth for single unit zirconia restoration resulted in better marginal adaptation than conventional using elastomeric impression.

Kumar A et al. (45) concluded that accurately fitting restoration requires good quality impression that depends upon skill of the operator and accurate impression techniques used. Impression distortion may be caused by the type of material used, the type of tray used, impression methods, storage circumstances, high seating pressure, and so on. The intraoral digital impression technique aids in CAD/CAM process. As a relatively new approach, dental products produced with intraoral digital impressions have demonstrated more accuracy than conventional impressions.

Zarbakhsh et al (46) did an in vitro experimental study to compare the accuracy of digital impression taking use of intraoral scanners versus conventional techniques. A typodont molar tooth was prepared as standard model and scanned by TRIOS intraoral scanner. After the study it was concluded that intraoral scanner had significantly higher accuracy than conventional method in all the references points (mesial , distal , buccal, and lingual). Thus, digital method can be used as an adjunct or alternative to increase the impression making.

Zarauz et al (47) compared the clinical results of fit of all-ceramic crowns fabricated from conventional silicone impressions with the fit of all-ceramic crowns fabricated from intraoral digital impressions (Itreo and Cadent) and reported that all – ceramic crowns fabricated with digital impressions with parallel confocal technology had clinically superior marginal fit compared to conventional impression restorations.

Chochlidakis et al (48) revealed in a systematic review that digital impression techniques was superior to conventional methods in terms of internal gap of fixed dental restorations but this difference was not statistically significant. Pooled data were statistically analysed, and factors affecting the accuracy of fit were identified, and their impact on accuracy of fit outcomes were assessed.

Patzelt et al [23] in their study found the trueness of 4 intraoral scanners ranging from 44.1mm to 591.8mm for edentulous arches and 38mm to 332.9mm for completely edentulous arches and concluded that except for one intraoral scanner, all other showed comparable levels of trueness values. The mean precision values of 4 IO scanners ranged from 21.6 to 698.0 μm and 37.9 to 99.1 μm for edentulous and completely edentulous arches respectively.

Flugge et al [24] evaluated the precision of digital intraoral scanning (Itreo) under clinical conditions of one patient with 10 full -arch impression and compared it with precision of extraoral (EO) digitalization with the help of polyether impression material and D250 extra oral scanner. Both the intraoral and extraoral scanning was done at the facial surfaces of anterior teeth and buccal surface of molars. The study concluded that EO scanning has higher precision (25 μm) than IO scanning (50 μm) suggesting that intraoral conditions contribute to the inaccuracies of a scan.

Oh et al [49] assessed the accuracy of three digitalization methods (DS; direct scanning, CS; cast scanning, and IS; impression scanning) on a complete arch that included several maxillary typodont preparation designs. The impressions were obtained with polyether impression material which were scanned with the help of tabletop scanner for IS scanning. For CS group definitive cast were obtained from the impressions and scanned. The findings suggested that IS method is more accurate digitalization technique for creation of virtual cast and trueness of individual abutments was affected by both the digitalization method and abutment location; digitalization method affected the trueness more than the abutment location.

Sim et al [51] compared the accuracy (trueness and precision) of fixed dental prosthesis models for three types of restoration - single crown, three-unit bridge, and inlay - and found that digital models had lower root mean square values of trueness of the entire arch and preparations than stone models. However, the accuracy of the complete arch and the trueness of the 3D printed model preparations were inferior compared to the other groups.

Haddadi et al [50] assessed the accuracy of intraoral scans and conventional impression measured at 6 points on a single tooth preparation. The statement of problem was most intraoral scanners had lesser accuracy at the preparation margins compared to smooth surfaces of the tooth preparation. At the preparation margin, the study concluded that

Trios 3 performed significantly better with discrepancy of only 15 μm than conventional impression and other intraoral scanners LAVA TDS, CEREC Omnicam, and CS3600 achieved equal margin accuracy while outperforming conventional impression and GC Aadva.

Mangano et al [17] presented an experimental strategy for capturing the margins of single prepared teeth with an intraoral scanner. The experiment was based on analogue-digital protocol and the protocol was based on scanning with IOS, outside the mouth, of a partial custom 3D-printed tray, physically relined on the abutment with polyvinylsiloxane light. The impression of the hollow portion of this tray was captured, the normal were inverted, and the file was superimposed on the mesh obtained directly in the mouth from an intraoral scan, replacing it. The clinical precision of monolithic zirconia crowns not only depends on the scan but also on series of steps (design, milling and sintering).

Keeling et al [53] investigated the impact of clinical factors on the quality of intraoral scans of crown margins and concluded that clinical factors limiting visibility have a substantial impact on the curvature (sharpness) of the margin measured by IOS. Confounding factors included the existence of adjacent teeth, proximity to gingivae, and wand location within the oral cavity. Regardless of scanning conditions, lingual margin curvature remained constant. When the buccal margin was situated equigingivally, the curvature of the buccal margin was greatly impacted. The existence of neighbouring teeth and proximity to the gingivae had a substantial effect on mesial border curvature. All three confounding factors had a substantial effect on distal margin curvature.

Son and Lee [51] found a significant difference in the accuracy of intraoral scanning according to finish line locations of the tooth preparation. The comparison was among the 4 finish line conditions- supragingival, equigingival , subgingival and subgingival with gingival retraction cord. Therefore, supragingival finish line or use of gingival displacement cord is recommended for clinically acceptable accuracy of marginal region captured by IOS.

Son and Lee [52] compared the accuracy of various 3D scanners according to types of teeth of dental arch and both the intraoral scanners and desktop scanners showed significant differences in the accuracy. The accuracy of intraoral scanners tends to get worse from anterior teeth to posterior teeth. The accuracy is worst with second molar with horizontal displacement in buccal direction towards posterior region with intraoral scanners whereas desktop scanners showed less horizontal displacement.

Son and Lee [51] evaluated the marginal and internal fit and intaglio surface trueness of interim crowns fabricated from tooth preparation scanned at 4 finish line locations and reported that marginal and internal fit significantly showed differences according to locations with best results with supragingival finish lines. Intaglio surface trueness was significantly different in the marginal region with highest value in subgingival locations. . Crowns fabricated on the subgingival finish line caused inaccurate marginal ft due to poor fabrication reproducibility of the marginal region.

Marotti et al [53] compared the accuracy of ultrasound impression taken of sub gingivally prepared teeth with the help of HFUS scanner and digital optical scanner and assessed that ultrasound digital impression was able to detect the subgingival margins of tooth preparation .

Nissan et al [54] conducted an in vivo study to compare the effect of two commonly used PVS impression techniques (1 step versus 2- step) on fitting of fixed dental prosthesis and evaluated that two-stage impression technique was the most accurate method of PVS impression making. The presence of saliva, tongue, and floor of mouth movement did not affect the accuracy of the impression technique, emphasising the superiority of the 2-stage technique.

Hoyos and Soderholm [55] used disposable plastic tray and metallic rim lock tray to determine how tray rigidity and impression techniques affect the accuracy of polyvinylsiloxane impressions. Later it was concluded that plastic tray produced less accurate impressions than metal tray and when metal trays were used , putty-based impressions were dimensionally better than heavy/light body impressions.

Levartovsky et al [56] in an experimental in vitro study found out that when the two step putty-wash impression technique, pouring of the impression may be postponed up to 30 hours, pouring should, however, be completed within 2 hours when employing the one step impression process.

Materials & Methodology

The current research was carried out in the Postgraduate Department of Prosthodontics and Crown and Bridge, Babu Banarasi Das College of Dental Sciences, Babu Banarasi Das University, Lucknow, with the aim to evaluate and compare the conventional impression with digital impressions (Direct, Partially direct, and Indirect) techniques for single natural tooth supported crowns. Attempts were made to standardize the procedures throughout the study to minimize effect of the variable factors on the observation and final result.

Ethical Committee Approval:

Prior to the study, approval was taken from the Ethical Committee Babu Banarasi Das College of Dental Sciences, Babu Banarasi Das University, Lucknow (IEC Code: 11)

Sample Study, Size and Distribution:

The sample for this study was Mandibular Right Molar Tooth on Nissin hard gingiva jaw model (32 teeth) [PR02001-UL-HD-FEM-32]

Total 61 samples were divided into 4 main groups which are Group RM, Group DD, Group PDD and ID. Group DD, Group PDD and ID contains 20 samples each.

Group RM* (control group)- Reference model

Group DD* - 20 scans of Nissin jaw model with intraoral scanner

Group PDD* – 20 scans of elastomeric impression with laboratory scanner

Group ID* - 20 scans of die stone cast with laboratory scanner

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RM*: Reference model; DD*: Intraoral scanning (Direct Digitalization)

PDD*: Laboratory impression scanning (Partially Direct Digitalization)

ID*: Laboratory cast scanning (Indirect Digitalization)

ARMAMENTARIUM FOR THE STUDY:

To conduct the study, armamentarium used are listed below:

1. Nissin Hard Gingiva Jaw Model* [Figure 1 (a)]
2. Metal Perforated Rim Lock Impression Trays^ [Figure 2 (b)]
3. Additional silicone impression material° [Figure 2 (a)]
4. Themisto TH-M61 Digital Vernier Calliper [Figure 3]
5. TYPE IV Dental Stone[α] [Figure 4]
6. Round diamond point bur[β] [Figure 5]
7. Tooth preparation bur[∞] [Figure 1 (b)]
8. Airotor[♫] [Figure 1 (c)]
9. Dental straight probe[♦] [Figure 1 (d)]
10. Electric Dental Vibrator[♣] [Figure 6]
11. Laboratory scanner[▼] [Figure 7]
12. Intraoral scanner[■] [Figure 8]

METHODOLOGY

For convenience and clarity of the study methodology have been described under the following headings:

A. Inclusion criteria
B. Exclusion criteria
C. Reference model preparation and dataset
D. Digital impression making
E. Assessment of accuracy of digital impression
F. Groups and dataset
G. Statistical analysis of data

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* PR02001-UL-HD-FEM-32; ^GDC No-4; °Aquasil, Denstply Caulk, USA; α Kalabhai Kalrock Die Stone

[β] MANI (INC), BR-46; [∞] Shofu crown and bridge preparation kit, SHOFU DENTAL INDIA PVT.LTD

[■] OMNICAM, CEREC, SIRONA, Germany; [▼] MEDITT-series Tabletop Scanner, Korea

[♣] Unident, instruments (India) Pvt. Ltd.; [♦]API dental probe; [♫]NSK Pana Air standard head chuck type

Figure 1: Armamentarium for tooth preparation

(a) Nissin Hard Gingiva Jaw Model; (b) Tooth preparation bur.
(b) (c) Airotor; (d) Dental straight probe

Figure 2: Armamentarium for impression making

(a) Additional silicone impression material
(b) Metal Perforated Rim Lock Impression Tray

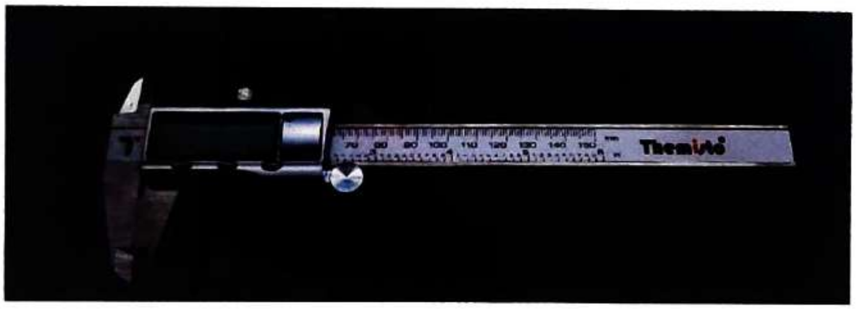


Figure 3: Themisto TH-M61 Digital Vernier Calliper

Figure 1: Armamentarium for tooth preparation

(a) Nissin Hard Gingiva Jaw Model; (b) Tooth preparation bur.
(b) (c) Airotor; (d) Dental straight probe

Figure 2: Armamentarium for impression making

(a) Additional silicone impression material
(b) Metal Perforated Rim Lock Impression Tray

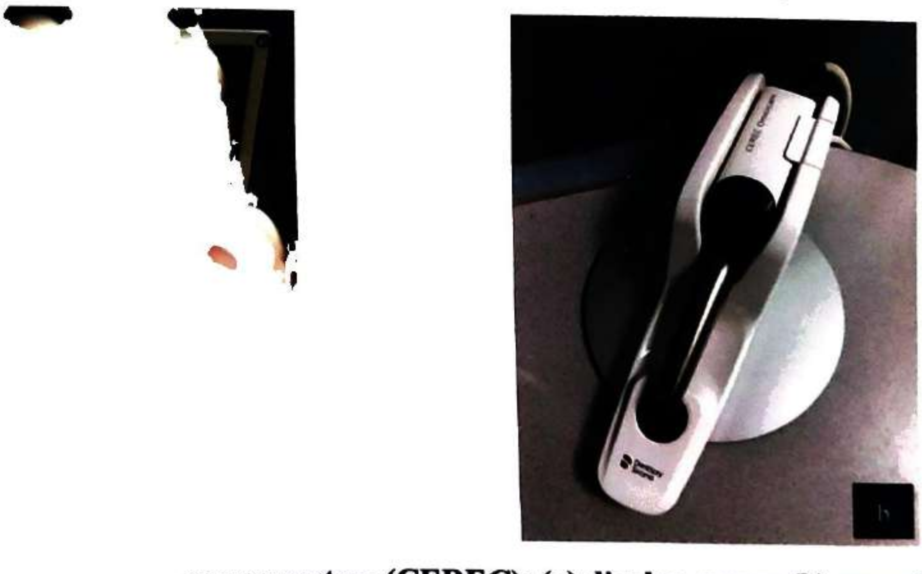
Figure 3: Themisto TH-M61 Digital Vernier Calliper

Figure 4: TYPE IV Dental Stone

Figure 5: Round diamond bur

Figure 6: Electric Dental Vibrator

Figure 7: Laboratory scanner



anner system (CEREC); (a) display screen (b) scanning device

A. INCLUSION CRITERIA

- Biomechanically prepared mandibular right molar for zirconia crown
- Polyvinylsiloxane impression of prepared mandibular right molar with well-marked indentations at pre specified positions.
- Die stone cast with no porosities or bubbles.
- Complete scans of typodont with prepared mandibular right molar
- Complete scans of Die Stone cast
- Complete scans of PVS impression

B. EXCLUSION CRITERIA

- Faulty tooth preparation
- Incomplete polyvinylsiloxane impression
- Faulty cast with bubbles or porosities
- Incomplete scans

C. REFERENCE MODEL PREPARATION AND DATASET

A typodont containing acrylic resin teeth was used and mandibular first molar was prepared following biomechanical principles with 1mm shoulder finish line, axial convergence of 6 degrees and 1.5 to 2mm of occlusal reduction to receive zirconia restoration (Figure 9 (a-d)). After the preparation of the tooth a round diamond point bur (*MANI INC, BR-46*) was used to make indentations in the centre of bucco-occlusal, mesio-occlusal, disto-occlusal, and linguo-occlusal line angles. The indentations were also made in the centre of mesio occlusal line angle of mandibular second molar and in the centre of disto-occlusal line angle of mandibular second premolar with a round diamond point bur (Figure 10).

A Digital Vernier calliper was used to measure the distance between the indentations on the reference model and a reference dataset were obtained in buccolingual direction and mesiodistal direction, mesio-proximal and disto-proximal direction respectively (Figure 11). To avoid the influence of bias, Reference Dataset were obtained by same examiner using vernier calliper.

Figure 9: Tooth preparation of mandibular right first molar using biomechanical principles

(a) 1mm shoulder finish line preparation with tapered flat end diamond bur
(b) Buccal view of prepared tooth
(c) Occlusal view of prepared tooth. Note the shoulder finish line margin for zirconia restoration.
(d) Occlusal clearance of 1.5 – 2mm to receive zirconia restoration.

Figure 10: Indentations made using round diamond bur (*MANI INC, BR-46*)

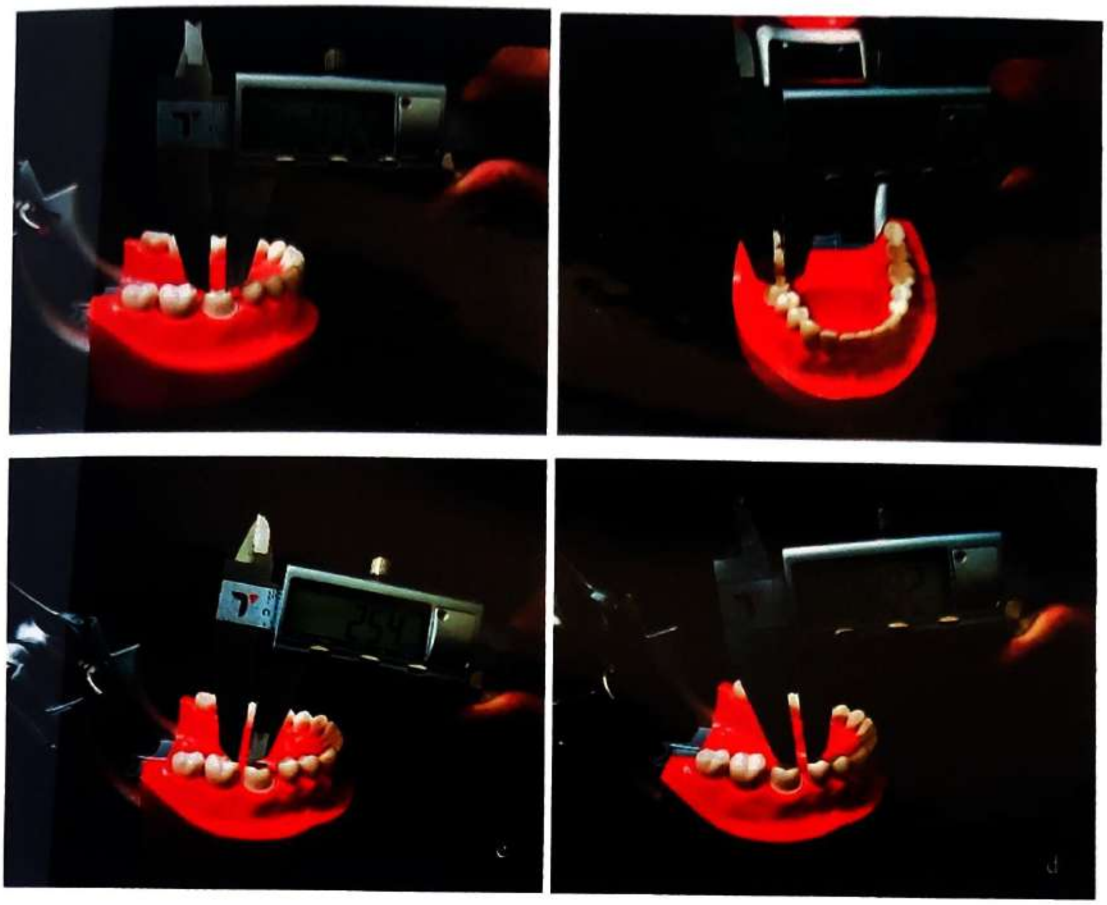


Figure 11: Measurement for Reference Datasets using Digital Vernier Calliper

(a) Mesiodistal distance (MD) (b) Buccolingual distance (BL)

(c) Distoproximal distance (DP) (d) Mesioproximal distance (MP)

D. DIGITAL IMPRESSION MAKING

Direct Digitalization: Intraoral Scanning

The typodont containing prepared mandibular first molar with indentations was positioned parallel to the ground and the sectional scan from distal aspect of mandibular right third molar to mesial aspect of mandibular right canine in continuous motion scanning technique was made. The experimental data sets were acquired by scanning the prepared tooth with indentations 20 times.

Partially Direct Digitalization: Impression scanning

The typodont containing the prepared mandibular first molar with indentations was positioned parallel to the ground, and a quadrant impression was created utilising a one - step putty wash procedure and a rim lock perforated impression tray (Figure 12). To avoid any reflection of the impression material when scanning with a desktop scanner, a small coating of anti-reflective spray was sprayed over the tissue surface of the impression.

The impression was held under the desktop scanner, and the scans .stl file was obtained on the computer using the pre-installed ExoCAD software compatible with the scanner system (Figure 13). The experimental data sets were acquired by making 20 quadrant impressions and scanning them 20 times respectively.

Figure 12: Quadrant impression using Additional Silicone impression material (Aquasil, Denstply)

Indirect Digitalization: Die stone cast scanning

A quadrant impression was made using a one-step putty wash method and a rim lock perforated impression tray, with the typodont containing the prepared mandibular first molar positioned parallel to the ground. To avoid abnormalities in the cast, the impression was poured after 1 hour using Type IV dental stone. After final set, the die stone quadrant cast was retrieved from the impression (Figure 14). The cast was held under a desktop scanner, and the scans. Stl file was obtained on the computer using the scanner's pre-installed ExoCAD software (Figure 15). The experimental data sets were acquired by producing 20 quadrant die casts and scanning them each 20 times.

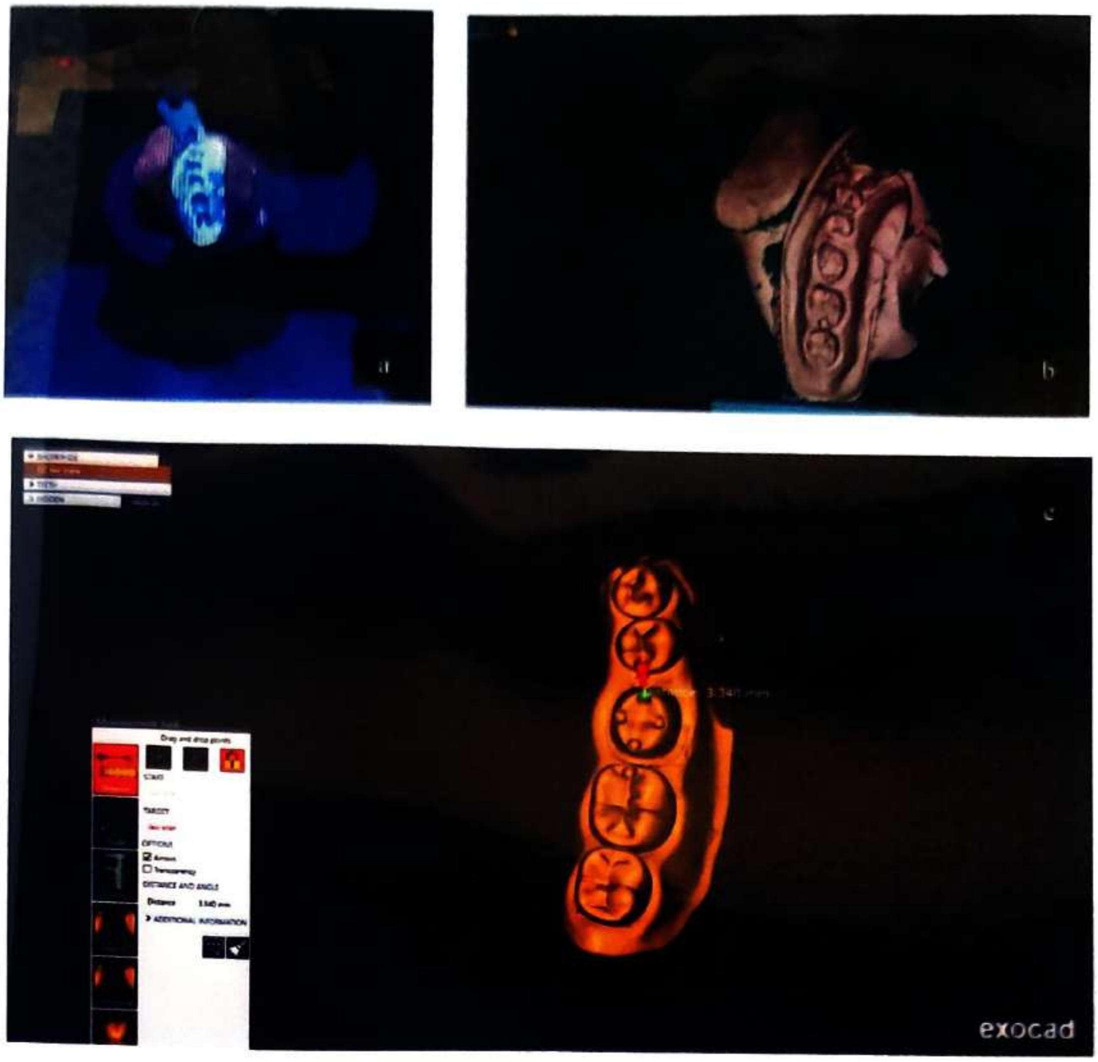


Figure 13: Impression scanning with Extraoral Scanner (MEDIT, Korea)

(a) Impression sprayed with single coating anti reflective spray and scanned under desktop scanner.
(b) Scanning under process to obtain .stl file.
(c) Scanning completed and stl file image obtained on ExoCAD software.

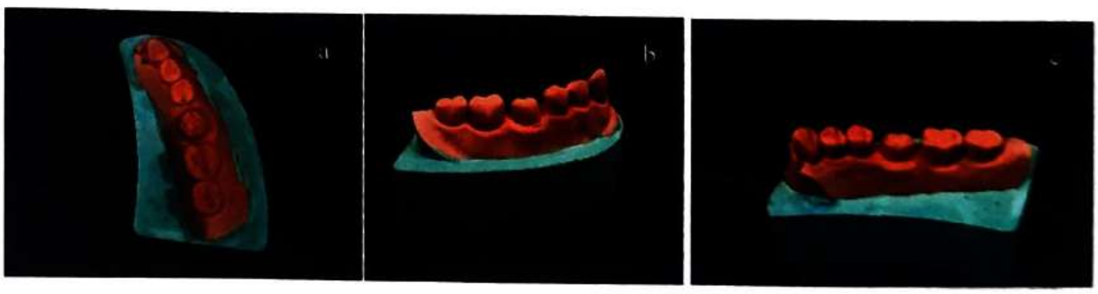


Figure 14: Die-stone cast retrieved from impression

(a) Occlusal view (b) Buccal view (c) Lingual view

Figure 15: Die-stone cast scanning with Extraoral Scanner (MEDIT, Korea)

(a) Placement of die-stone cast on platform of scanner

(b) Scanning of die-stone cast in progress

(c) Production of .stl file image on ExoCAD software

E. ASSESMENT OF ACCURACY OF DIGITAL IMPRESSION

The 20 experimental data sets obtained through direct digitalization (DD) were transferred to preinstalled software that was compatible with the CEREC intral oral scanning system.

With the use of software generated calibrated digital calliper, the indentations on the scans were employed as a reference point for measuring linear dimension in the buccolingual, mesiodistal, mesio-proximal, and disto-proximal directions.

These datasets were measured by measuring the distance between the inner edge on one side of the indentation and the inner edge on the opposite side, buccolingually (BL) and mesiodistally (MD) of the prepared tooth, mesio-proximally (MP) and disto-proximally (DP) of the prepared tooth and adjacent tooth. (Figure 16)

The 20 experimental data sets obtained using Partially direct digitalization (PDD) and Indirect digitalization (ID), respectively, were transferred to preinstalled ExoCAD software compatible with MEDIT desktop scanner. The data sets were measured in the same way that the direct digitization approach was. (Figure 17)

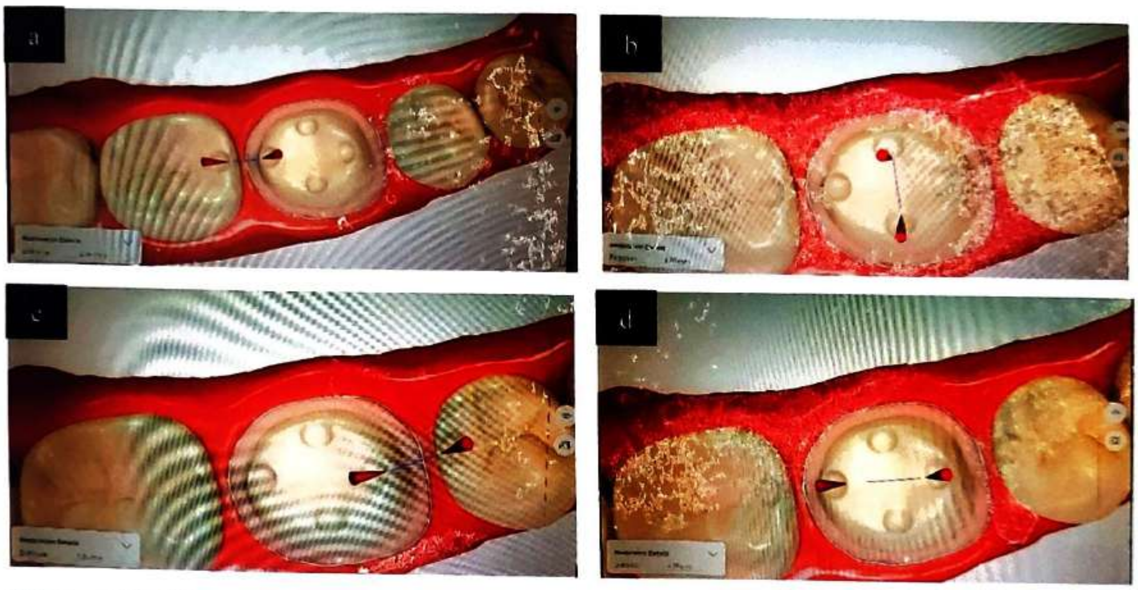


Figure 16: Measurement of Intraoral scanning datasets using installed calibrated calliper in CEREC, Omnicam scanner

(a) Disto-proximal measurement

(b) Buccolingual measurement

(c) Mesio-proximal measurement

(d) Mesio-distal measurement

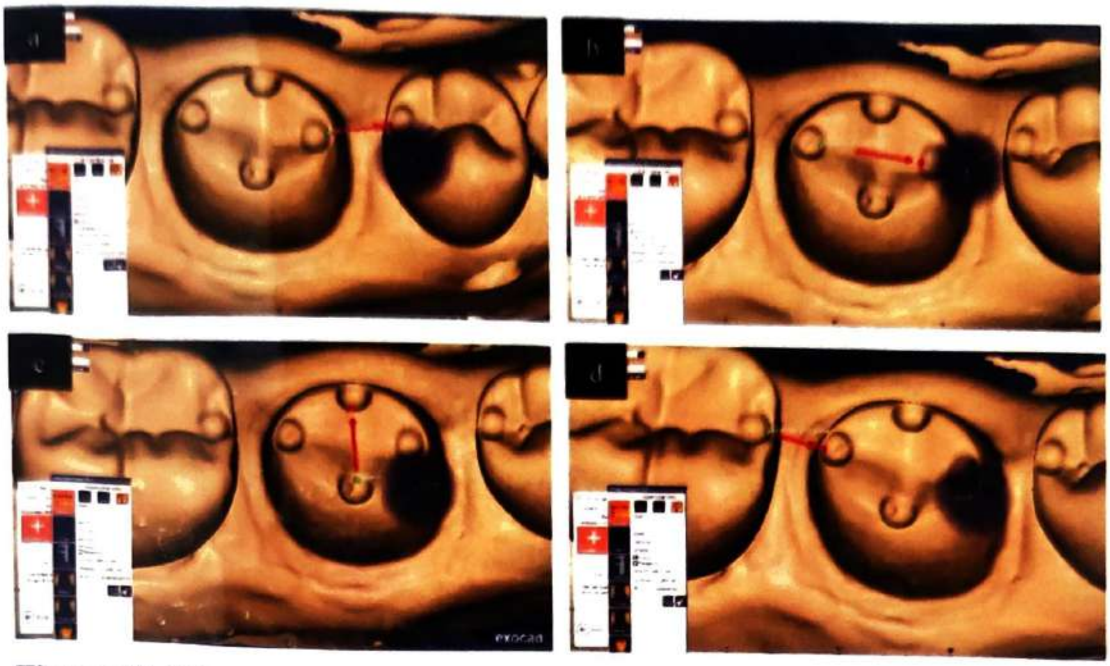


Figure 17: Measurement of Extraoral scanner datasets using installed calibrated calliper in ExoCAD software

(a) Mesio-proximal measurement

(b) Mesio-distal measurement

(c) Bucco-lingual measurement

(d) Disto-proximal measurement

F. GROUPS AND DATASETS

As defined by ISO-5725-1:1994, accuracy of scanners consists of trueness and precision. Figure 18, summarize the present study method.

- A comparative evaluation between Group RM and Group DD were done to evaluate the trueness and the values of Group DD were intra-compared to check the precision.
- A comparative evaluation between the Group RM and Group PDD were done to evaluate the trueness and the values of Group PDD were intra- compared to check the precision.
- A comparative evaluation between the Group RM and Group ID were done to evaluate the trueness and the values of Group ID were intra- compared to check the precision.

G. STATISTICAL ANALYSIS OF DATA

The data for the present study was entered into Microsoft Excel 2007 and analysed using the SPSS statistical software 23.0 Version. The descriptive statistics included mean, standard deviation. The level of the significance for the present study was fixed at 5%.

The intergroup and intragroup comparison for the difference of mean scores between independent groups was done using the One Way ANOVA and independent t test.

The Shapiro–Wilk test was used to investigate the distribution of the data and Levine's test to explore the homogeneity of the variables. The data was discovered to be homogeneous and normally distributed. For each variable, the mean and standard deviation (SD) were calculated.

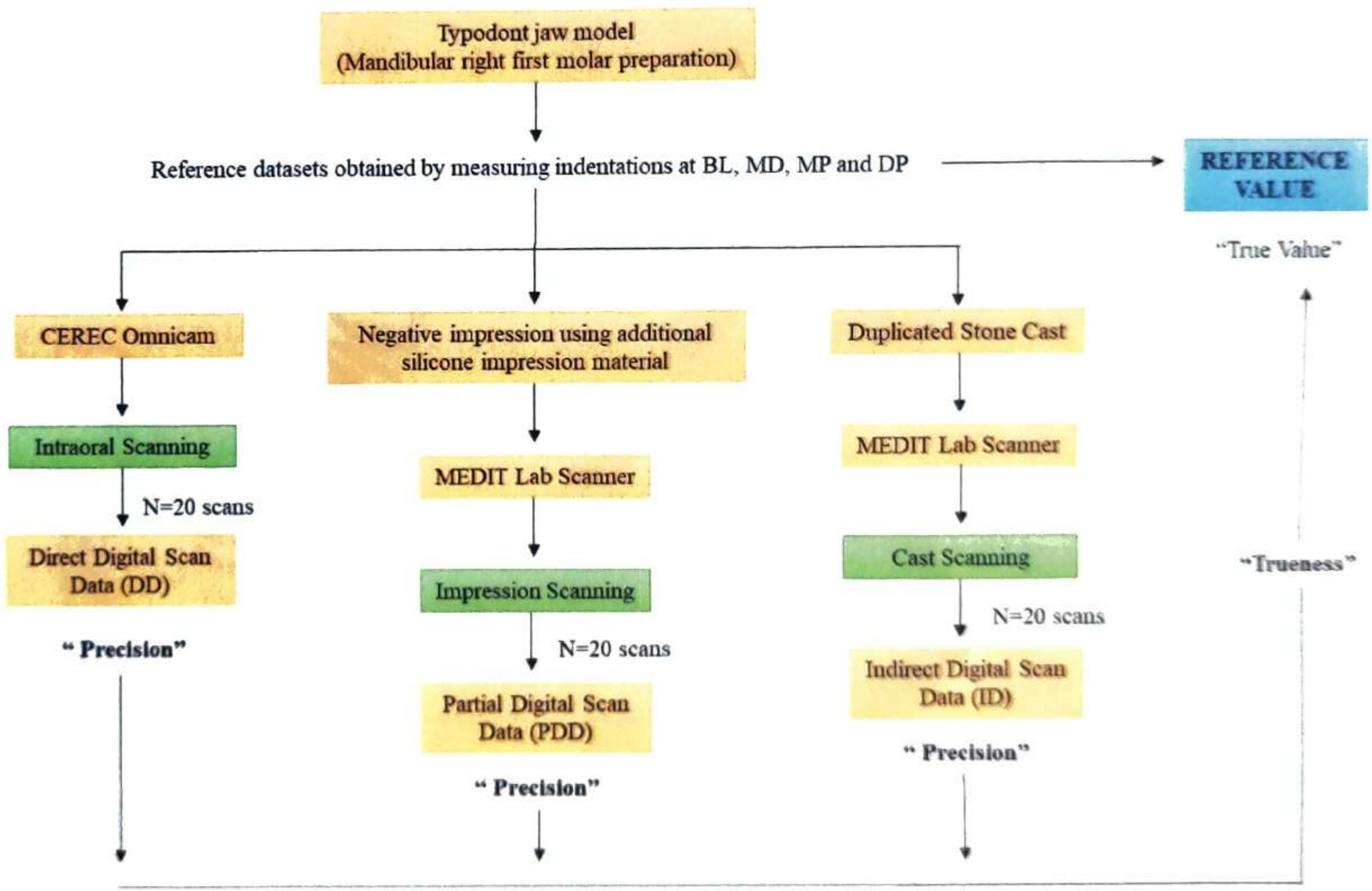


Figure 18: Diagram of the study method. Precision and trueness were used to assess accuracy.

Observations & Results

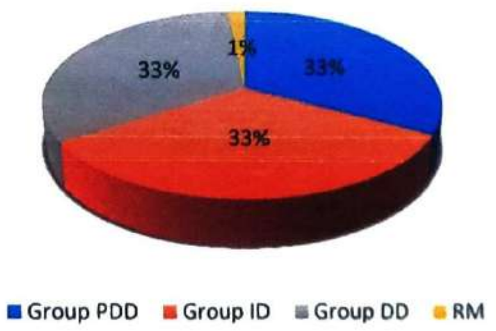
The current study was conducted as per the discussed material and methodology to evaluate and compare the accuracy of conventional and digital impression techniques which consists of trueness and precision.

The samples were allocated in 3 groups as follows:

S. No	Group	Description	No. of Samples
1.	Group PDD (Partially Direct Digitalization)	Samples made by scanning qudrant impresssion directly under Desktop Scanner	20 scans
2.	Group ID (Indirect Digitalization)	Samples made by Scanning quadrant die stone cast directly under Desktop Scanner	20 scans
3.	Group DD (Direct Digitalization)	Samples made by scanning typodont jaw model with the help of Intraoral Scanner	20 scans
4.	Group RM (Reference Model)	Reference model with prepared typodont mandibular right first molar	1

Table 1: Group wise distribution of Samples

Graph 1: Group wise distribution of samples in percentage



Out of a total of 61 samples included in the assessment , a total of 20 scans (33.33%) were made by scanning the 20 impressions of the prepared first mandibular right molar recorded by analogue impression technique directly under the desktop scanner. These comprised of Group PDD of the study.

A total of 20 scans (33.33%) were scans of quadrant die stone cast made by analogue impression technique and poured with Type IV dental stone. The quadrant die stone cast was directly scanned under desktop scanner and comprised of Group ID of the study.

Another 20 scans (33.33%) were direct scans of prepared typodont teeth with the help of intraoral scanner and comprised of Group DD of the study.

The typodont with prepared mandibular first molar tooth which was used to assess the accuracy of above impression technique comprised of Group RM

ASSESEMENT FOR PRECISION OF DIGITAL IMPRESSIONS

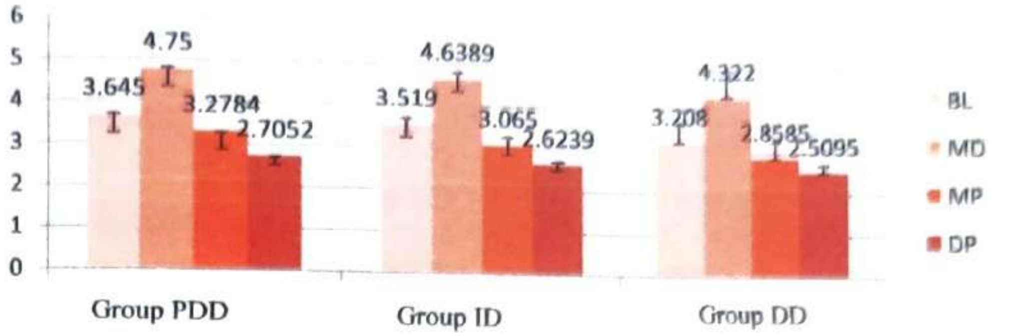
The precision of digital impression techniques was evaluated by intra-comparing 20 datasets from the groups PDD, ID, and DD at BL, MD, MP, and DP distances and analysing mean values and standard deviations. (Table 2, Graph 2)

	BL	MD	MP	DP	P value
Group PPP	3.645±0.066	4.75±0.088	3.278±0.105	2.705±0.066	0.001 (Sig)
Group ID	3.519±0.085	4.638±0.068	3.065±0.057	2.623±0.093	0.001 (Sig)
Group DD	3.208±0.055	4.322±0.046	2.858±0.048	2.509±0.042	0.001 (Sig)

Table 2 : Mean and Standard Deviation for Precision values of Digital Impressions (PDD,ID,DD)

The table depicts comparison of all the digital impressions in terms of their precision values. There was statistically significant difference between the precision values of these digital impressions at different linear distances (BL,MD, MP, and DP). ($p<0.05$)

The mean values in the Group PDD (BL) were 3.6450, in the Group ID was 3.5190, in the Group DD was 3.2080. At the Mesio Distal (MD), mean values in the Group PDD was 4.7500, in the Group ID was 4.6389, in the Group DD was 4.3220. At the Mesio Proximal (MP), mean values in the Group PDD was 3.2784, in the Group ID was 3.0650, in the Group DD was 2.8585. At the Disto-Proximal (DP), mean values in the Group PDD was 2.7052 , in the Group ID was 2.6239, in the Group DD was 2.5095. The intragroup comparison between the experimental groups were statistically significant when analysed using the One Way ANOVA. The means and standard deviation demonstrate a statistically significant (0.001) difference between the various linear distances of different Digital impressions (Table-2).



Graph 2 : Graphical Representation of Precision values of different Digital Impressions

The mean of precision values at BL, MD, MP, and DP distances of 3 different digital impressions is represented in this Graph 2 . The lowest mean values show less deviation and more precision when groups were intra-compared.

		Mean	Std. Deviation	Std. Error	Minimum	Maximum	P value
Avg	Group **PDD**	3.4617	.03273	.00624	3.38	3.52	0.001 (Sig)
	Group **ID**	3.5947	.03693	.00826	3.45	3.72	
	Group **DD**	3.2245	.02389	.00534	3.19	3.26	

Table 3: Intragroup comparison of average values for Precision

Following 20 repetitions of the repetitive scanning for each group, the final precision values for Group PDD, Group ID, and Group DD were evaluated in Table 3.

The mean values in the Group PDD were 3.4617, in the Group ID was 3.5947, in the Group DD was 3.2245. The intergroup comparison between the groups was statistically significant when analysed using One Way ANOVA at p value of 0.001 (Table-3)

The standard deviation in the Group PDD was 32μm, 36 μm in Group ID and 23 μm in Group DD (Table-3). There was statistically significant difference noted between the precision values of different digital impression techniques ($p<0.5$)

Based on the results of Table -3 , the descending order of precision in distinct groups is as follows:

Group DD > Group PDD > Group ID

Intraoral scanning > Impression scanning > Cast scanning

ASSESEMENT FOR TRUENESS OF DIGITAL IMPRESSIONS WHEN COMPARED TO REFERENCE VALUES

To evaluate the accuracy of digital impressions, the reference dataset obtained by measuring test distances with a digital calliper was compared to the mean and standard deviation obtained from intraoral scanning (Group DD), impression scanning (Group PDD), and cast scanning (Group ID) (Table 4, Graph 3)

The mean and standard deviation of the trueness values for the IO scanner and EO scanner are shown in the Table-4. When the scanners were compared with a reference model values, a statistically significant difference was seen ($p< 0.05$)

The mean values in the Group PDD (BL) were 3.6450, in the Group ID was 3.5190, in the Group DD was 3.2080.The intergroup comparison with the reference value of typodont model with prepared tooth was statistically significant when analysed using independent t test.(Table-4)

At the Mesio Proximal (MP), mean values in the Group PDD was 3.2784, in the Group ID was 3.0650, in the Group DD was 2.8585. The intergroup comparison with the reference value of typodont model with prepared tooth was statistically significant when analysed using independent t test.(Table-4)

At the Disto-Proximal (DP), mean values in the Group PDD was 2.7052 , in the Group ID was 2.6239, in the Group DD was 2.5095. The intergroup comparison with the reference value of typodont model with prepared tooth was statistically significant when analysed using independent t test (Table-4)

At the Disto-Proximal (DP), mean values in the Group PDD was 2.7052 , in the Group ID was 2.6239, in the Group DD was 2.5095. The intergroup comparison with the reference value of typodont model with prepared tooth was statistically significant when analysed using independent t test (Table-4)

When compared to the Reference Model's deviation (SD=60μm), the deviations for Groups PDD, ID, and DD at BL direction were 66 μm, 85 μm, and 55 μm, respectively (Table-4). When analysed using independent t test , there was significant difference found between the Groups PDD, ID and DD at BL distance when compared to the Reference value (p=0.001)

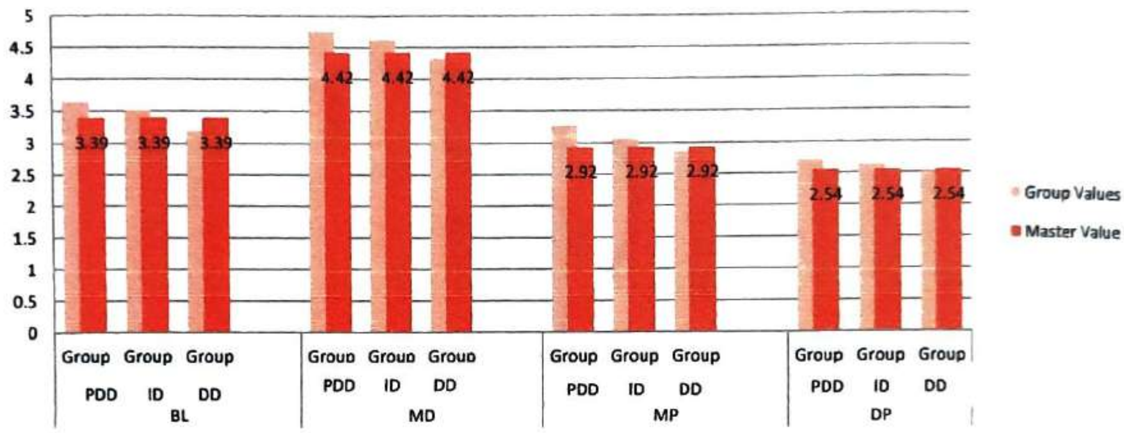
		Group Values	Master Value	P value	Significance
BL	Group **PDD**	3.64±0.066	3.39±0.06	0.001	Significant
	Group **ID**	3.51±0.085	3.39±0.06	0.001	Significant
	Group **DD**	3.20±0.055	3.39±0.06	0.001	Significant
MD	Group **PDD**	4.75±0.088	4.42±0.08	0.001	Significant
	Group **ID**	4.63±0.068	4.42±0.08	0.001	Significant
	Group **DD**	4.32±0.046	4.42±0.08	0.003	Significant
MP	Group **PDD**	3.27±0.105	2.92±0.046	0.001	Significant
	Group **ID**	3.06±0.057	2.92±0.046	0.001	Significant
	Group **DD**	2.85±0.048	2.92±0.046	0.003	Significant
DP	Group **PDD**	2.70±0.066	2.54±0. 043	0.001	Significant
	Group **ID**	2.62±0.083	2.54±0. 043	0.001	Significant
	Group **DD**	2.50±0.042	2.54±0.043	0.049	Significant

Table 4: Comparison for Trueness values of Digital scanners with Reference values of typodont model

When compared to the Reference Model's deviation (SD=80μm), deviations observed at MD direction were 88 μm, 68 μm, and 46 μm for Groups PDD, ID, and DD, respectively (Table-4). There was a significant difference found between the Group ID and Group PDD at MD distance when compared to the Reference Model (p=0.001), although the difference was somewhat greater for Group DD (p=0.049).

When compared to the Reference Model's deviation (SD= 46µm), deviations observed at MP direction were 105 µm, 57 µm, and 48 µm for Groups PDD, ID, and DD, respectively (Table-4). There was a significant difference found between the Group ID and Group PDD at MP distance when compared to the Reference Model (p=0.001), although the difference was somewhat greater for Group DD (p=0.003)

When compared to the Reference Model's deviation (SD= 43µm), the deviations for Groups PDD, ID, and DD at DP direction were 66 µm, 83 µm, and 42 µm, respectively (Table-4). When analysed using independent t test , there was significant difference found between the Group PDD and Group ID at BL distance when compared to the Reference value (p=0.001), although the difference was somewhat greater for Group DD (p=0.049)



Graph 3: Graphical representation for comparing Trueness values of Group values with Reference values

Based on Table 4 and Graph 3, the descending order of trueness of distinct groups when compared to reference values is as follows:

Group DD > Group ID > Group PDD

Intraoral scanning > Cast scanning > Impression scanning

Discussion

The effectiveness and quality of prosthesis greatly depends on the impression's accuracy in capturing the tooth, neighbouring tooth, and soft tissues besides other factors like impression technology and technique, material , restorative material to name a few.

Making conventional impressions with elastomeric impression materials is still the most often utilised approach for reproducing intraoral anatomy and transferring this information to the dental laboratory for production of indirect dental restorations [13]. In a bid to overcome the limitations of traditional approach such as tearing and deformation of impression, patients discomfort as the material is greasy and unpleasant, errors in tray selection, tray adhesive application, required disinfection and storage space constraints, dentistry has advanced to new heights with the introduction of computers and concomitant advancements[57].

An impression is described as "a negative likeness or copy in reverse of the surface of an object; an imprint of the teeth and adjacent structures for use in dentistry" whereas digital impression is not a negative likeliness or copy in a reverse of the surface of an object[58].

According to an American Dental Association Clinical Evaluator Panel study [22] in the year 2021, 53% of clinicians presently utilise the IOS system to increase clinical efficacy and laboratory communication, while 47% refuse to use it due to the large cost commitment. The most common IOS therapy was single tooth supported crowns (60%).

Digital impressions, in example, resulted in significant improvements in impression production as it allows dentists to create realistic, machine generated recreations of soft and hard tissues in the jaw. In a practical sense, IOS offers several advantages such as minimising patient pain and suffering, lowering operator workload and danger of infections and cross infections, analysing abutment tooth and restoration, assessing tooth and gum colour tone, reducing cost and material waste, and so on[14].The accuracy of crowns fabricated with digital impressions have been found to be either similar[1] or equal or more accurate than the ones fabricated with conventional-impression and indirect methods with working models[37]

There are several aspects that influence scanning outcomes and data collecting. One of the aspects is different scanning approaches which might alter the accuracy of results[23]. Different scanning systems have been observed to lead to varying experimental outcomes[24]. Furthermore, extraoral scanner accuracy is affected by impression material selection and operating duration, whereas intraoral scanner accuracy is affected by scanning range, light[25], and oral tissue [26,27].

Although IOS usage is growing along with the market's size, for the majority of clinicians, the installation process, the high cost, and the ongoing software renewal make it impractical. Therefore, using a laboratory scanner for CAD-CAM restorations is a more cost-effective method. With these scanners, the clinicians can take a conventional impression, and the working cast is sent to a lab to produce a digital image.

There are three methods to utilize digital impressioning systems[49]:

1. Use of intraoral scanner
2. Recording the impression and scanning the impression using lab scanner
3. Recording the impression and scanning the poured cast using lab scanner

The present study evaluated and compared the accuracy of conventional impression techniques to digital impression techniques for single natural tooth supported crowns by scanning the prepared typodont teeth with an intraoral scanner and scanning the gypsum casts and impressions with a tabletop scanner.

The accuracy of a digital dental impression is governed by two factors: "trueness" and "precision." Trueness is defined as the comparison between a reference dataset and a test dataset. Precision is defined as a comparison between various datasets obtained from the same object using the same scanner[37]. The more precise the measurement, the more predictable the result. A high trueness yields a result that is near to or equal to the measured object's true value.

For the reference dataset, a mandibular right first molar was biomechanically prepared on typodont using a 1mm shoulder finish line, 6 degrees of axial convergence, and 1.5-2mm of occlusal reduction to receive zirconia restoration[59,60]. When dealing with monolithic zirconia crowns in a purely digital method, it is critical to design and produce a restoration that perfectly fits and closes on marginal lines of prosthetic abutments. Although the clinical precision of a monolithic crown is determined by a succession of following procedures (data acquisition ,design, milling, sintering), the initial step with IOS is to achieve a correct optical impression.

A well-defined supra gingival finish line is critical for optical impressioning(29,51). Although finish line design has little impact on the marginal gap for monolithic zirconia crowns , it enhances the fracture strength of these crowns when the finish line is conservative (61–63) . For monolithic zirconia crowns, a shoulder preparation margin design with 0.6–1.2 mm of finish line width(64) is sufficient to provide adequate flexural strength because it can withstand fracture loads better because the circumferential shoulder can withstand occlusal forces, resulting in less stress concentration on the axial walls (65,66).

The influence of the traditional impression's technique on the correct fit of restorations is widely debated in the dental literature. Many authors emphasize on single step impression approach(36,67–69) while others believe that the two-step impression procedure provides greater dimensional accuracy(71-73). Dimensional accuracy is determined not just by the manner of impression method utilised, but also by the type material used. To attain a greater dimensional precision, Aquasil PVS imprint material was employed in this study. It has been demonstrated that Aquasil additional silicone impression material show less dimensional change than other PVS materials (30)

Despite the market's abundance of intraoral scanners, Dentsply SIRONA offers a whole spectrum of products, from scanners to milling units, suggesting a more precise and accurate intraoral scanning technology(70–74). The CEREC Omnicam intraoral scanner with quadrant scanning approach was employed in this study, which works on the principle of active triangulations and is thus impacted by the scanning strategy as documented in the literature (34). The continuous strategy was the suggested strategy for image accuracy. Because the intraoral scanner creates the complete video by continually shooting the region in a short range, it has been claimed that the longer the scanning range, the higher the mistake in accuracy(70,75,76).The scanning approach is one of the variables that determines the accuracy of an IOS. Various scanning strategies are described in the literature for complete denture prosthesis, single crown and fixed partial restorations, and implant impressions(32–34). A recent research(71) underlined the need of minimising rotations and vertical movements of the scanner head, since a change in direction may impair the image stitching process.

The present study measured the accuracy through indentations marked with round bur on line angles to improve measurement accuracy, since literature indicates that measurements were more precise on pin point references than cross grooves [77]. Image modification increases when enormous amounts of data or faulty images are merged, reducing precision [78], Measurements between the indentations on the reference model were obtained manually by a single operator using a digital vernier calliper, as employed in the work by Sason et al[31]. Furthermore, this apparatus was capable of measuring linear dimensions with 0.01mm precision. Also, to avoid operator's bias, the linear distances between the indentations on the scan were measured using a calibrated linear measurement tool provided by the scanner software, and the places of measurement were noted manually by a single operator.

The purpose of assessing MP and DP distances was to determine the accuracy of the interproximal fit of the crown that would be fabricated later through digital approach. Similarly, the purpose of assessing BL and MD distances was to determine the accuracy of the internal fit of the crown.

Several studies have employed superimposition with varied total scan counts, ranging from 3 scans to 30 scans[79–82], although there is no reason provided for the same. 20 sets of scanning data were chosen for each group in the present study.

The proximal contact sites of the teeth play an important role in the effective outcome of crown restoration. The area of a tooth that is in close association, connection, or contact with an adjacent tooth in the same arch has been defined as the interproximal contact area[91]. Periodontal pockets, calculus deposition, ill-fitting edges of dental restorations, proximal carious lesions, food entrapment, and plunger cusp can all develop from loose or open proximal contact[92,93]. As a result, preserving proximal contact with the optimum interproximal fit of the crown is critical. This is first study of its kind where scans of occlusal proximal accuracy with the adjacent teeth was evaluated. Table-2 compared amongst groups and tabulated the MP and DP distances, the decreasing order of precision at Mesioproximal distance for is as follows: Intraoral scanning>Cast scanning>Impression scanning; however, the order of precision at Distoproximal distance is as follows: Intraoral scanning> Impression scanning >Cast scanning. The standard deviations were 48 μm at MP and 42 μm at DP for IOS (see Table-2) and the deviations were closest to the reference model values (see Graph-5), suggesting that crowns fabricated via IOS would have better interproximal fit and better and predictable proximal contact with adjacent tooth , than crowns fabricated with partially direct and indirect method. Hence, the intraorally scanned preparation crowns would fit better, require less interproximal and occlusal modification, and save 33% of the time at the crown seating visit [24,94,95] .

The scanning angulation and method[78] used at the BL distance were likely to be responsible for the larger deviations seen in Group DD (Table-2), whereas the position[87] of the abutment tooth and its larger volume and area[88] were probably responsible for those observed at the MD distance.

According to Table 3, IOS had better precision for all the four distances than the other groups, proving the accuracy of intraoral scanners. Similar to this, numerous investigations have discovered that intraoral scanners are more precise than lab scanners[31,71,75,83,84]. The deviations observed in the study for Group DD was 23μm. Several other studies[11,17,70,73,74] investigated the preciseness of CEREC intraoral scanner and found standard deviations ranging from 29 μm to 89 μm. A lower standard deviation found in this study implies that the CEREC Omnicam's precise has improved due to continuing technological advancements. The precision obtained in Group ID was less due to inaccuracies in the cast production process. Dental stone expands by around 0.07% to 0.10%,shrinks elastomeric impression materials shrinks by about 0.15 to 0.5% [85,86], this leads to inaccuracies in the cast. The cast scanning is slightly less precise and is related to the compensatory relationship between contraction and expansion. In the digitization of traditional impressions, antirefleclant spray plays a crucial function. According to Luthard et al., spray can result in inaccuracies of up to 40 μm[68], so should be used cautiously with impression scanning.

Regarding Trueness amongst the groups, there were statistically significant differences in the trueness of digital impression procedures when compared to reference values (p 0.001).Table-4, shows that the intraoral scanner had better trueness than the two scans obtained with EO scanner because its mean trueness value was closest to the actual measurements obtained from the reference model. The trueness of IOS, when compared to Reference model, revealed a standard deviation of 40 μm, with a range of 42 μm - 55 μm at different directions (see Table-4); which was in close comparison with other studies for short span scans [11,89,90]

A crown's fit is critical to its clinical success. Internal fit is closely related to crown retention and resistance properties[96].Larger misfit values not only reduces the retention but also increase the likelihood of fracture under stress[97]. Various qualitative and quantitative tools, such as 2D linear measurements of points on the occlusal surface and 3D compare analysis with coordinate measuring machine, have been used to assess the internal fit of crowns fabricated using complete digital workflow, partial workflow, or semi-partial workflow. The current study, however, used linear measurement of the depression made on the occlusal surface of the prepared mandibular right first molar tooth to receive a zirconia crown. Measurements were recorded as BL distance and MD distance in all groups, and post assessment (see Table-4) , the order of accuracy for internal fit at BL is as follows- Intraoral scanning> Impression scanning> Cast scanning; however, at MD the order of accuracy is as follows: Intraoral scanning> Cast scanning> Impression scanning. IOS had the lowest deviations for BL and MD, respectively, of 55 μm and 46 μm, while extraoral scanner had deviations ranging from 66 μm to 88 μm, which was in line with other research'[50,98–101] range of values.

In accordance with the American Dental Association (ADA No. 8, ADA 1970/71)[102] the internal misfit must be <150 μm. As a result, the three impressioning technique used in the study would provide a clinically acceptable prosthesis fit, well within the reference value <150 μm.

The null hypothesis was rejected, and a statistically significant relationship between the type of impression techniques and their accuracy was found. Single crowns fabricated from IOS, would exhibit better precision and proximal contact of prothesis, thereby would be more accurate when compared to extraoral scanners.

Limitations and future scope of the study:

1. The investigation was conducted in vitro, and patient factors such as saliva, patient movement, fogging of the intraoral camera lens, changes in scanning angulations of composite oral structures, humidity, and restricted space will impede intraoral scanner acquisition. In vivo studies need to be conducted to assess the same.
2. The position of each tooth in the arch may affect the accuracy of the scan , so more such studies need to be conducted.
3. A single intraoral scanner, a single impression material, and a single extraoral scanner were used in the investigation. Future research should assess the accuracy of various scanners and impression materials.
4. In this investigation, 2D measurement (linear) served as the standard measurement value. Future studies must examine the accuracy of any digital scanner using 3D Compare analysis, which is seems to be more appropriate.
5. Although crown fabrication is suggested to evaluate internal and proximal fit accuracy, it was not feasible within the scope of this study, hence a digital imprint was chosen for evaluation.

Clinical Implications:

The intraoral scanned images would deliver a better fit prosthesis over lab scanned images. The accuracy of a digital single restoration is typically measured by its proximal contact area fit and internal fit, with IOS continuing to outperform in these areas.

Conclusion

Under the limited conditions of the study , the following conclusions were drawn:

1. There was statistically significant difference ($p<0.5$) between accuracy of conventional and digital impressions.
2. Scans achieved by IOS exhibited greatest precision, with least SD of 23µm compared to lab scanner.
3. The descending order for precision amongst extraoral scanner were as follows: impression scanning > cast scanning; and the precision amongst the groups differed statistically ($p=0.001$)
4. Scans achieved by IOS exhibited highest trueness with SD ranging from 42µm-55µm, when compared with reference model values.
5. The trueness differed significantly ($p=0.001$) among the extraoral scanner groups in the following order: cast scanning> impression scanning.
6. Single crowns fabricated from IOS would exhibit better precision and better proximal contact of the prosthesis
7. Keeping the misfit reference value <150 µm, prosthesis fabricated by both intraoral scanner and extraoral scanner are clinically acceptable .

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Annexures

ANNEXURE I

BABU BANARASI DAS COLLEGE OF DENTAL SCIENCES (FACULTY OF BBD UNIVERSITY), LUCKNOW

INSTITUTIONAL RESEARCH COMMITTEE APPROVAL

The project titled **"Conventional Impression Versus Extraoral and Intraoral Scans – A Comparative In-Vitro Evaluation"** submitted by Dr **Akanksha** Post graduate student from the **Department of Prosthodontics and Crown & Bridge** as part of MDS Curriculum for the academic year 2020-2023 with the accompanying proforma was reviewed by the Institutional Research Committee present on **11th October 2021** at BBDCODS.

The Committee has granted approval on the scientific content of the project. The proposal may now be reviewed by the Institutional Ethics Committee for granting ethical approval.

Prof. Vandana A Pant
Co-Chairperson

Prof. B. Rajkumar
Chairperson

ANNEXURE II

Babu Banarasi Das University
Babu Banarasi Das College of Dental Sciences,
BBD City, Faizabad Road, Lucknow – 226028 (INDIA)

Dr. Lakshmi Bala
Professor and Head Biochemistry and
Member-Secretary, Institutional Ethics Committee

Communication of the Decision of the IXth Institutional Ethics Sub-Committee

IEC Code: 11 **BBDCODS/04/2022**

Title of the Project: Conventional impression versus extraoral and intraoral scans - A comparative in-vitro evaluation.

Principal Investigator: Dr Akanksha **Department:** Prosthodontics and Crown & Bridge

Name and Address of the Institution: BBD College of Dental Sciences Lucknow.

Type of Submission: New, MDS Project Protocol

Dear Dr Akanksha,

The Institutional Ethics Sub-Committee meeting comprising following four members was held on 07th April, 2022.

1.	Dr. Lakshmi Bala Member Secretary	Prof. and Head, Department of Biochemistry, BBDCODS, Lucknow
2.	Dr. Amrit Tandan Member	Prof. & Head, Department of Prosthodontics and Crown & Bridge, BBDCODS, Lucknow
3.	Dr. Rana Pratap Maurya Member	Reader, Department of Orthodontics, BBDCODS, Lucknow
4.	Dr. Akanksha Bhatt Member	Reader, Department of Conservative Dentistry & Endodontics, BBDCODS, Lucknow

The committee reviewed and discussed your submitted documents of the current MDS Project Protocol in the meeting.
The comments were communicated to PI thereafter it was revised.

Decisions: The committee approved the above protocol from ethics point of view.

Forwarded by:

Lakshmi Bala

(Dr. Lakshmi Bala)
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ANNEXURE III

MASTER CHART

- ***REFERENCE DIE STONE CAST (CONTROL GROUP)***

Buccolingual Distance (BL)	Mesiodistal Distance (MD)	Mesio-proximal Distance (MP)	Disto-proximal Distance (DP)
3.39	4.42	2.92	2.54

- ***EXTRAORAL SCANNING (GROUP PDD)- impression scanning***

Samples	Buccolingual Distance (BL)	Mesiodistal Distance (MD)	Mesio-proximal Distance (MP)	Disto-proximal Distance (DP)
1	3.550	4.640	3.265	2.688
2	3.708	4.604	3.234	2.620
3	3.540	4.629	3.082	2.598
4	3.568	4.792	3.281	2.661
5	3.653	4.724	3.156	2.719
6	3.615	4.807	3.228	2.722
7	3.596	4.853	3.387	2.837
8	3.630	4.746	3.356	2.717
9	3.646	4.677	3.121	2.731
10	3.719	4.763	3.340	2.740
11	3.687	4.742	3.210	2.758
12	3.634	4.776	3.230	2.716
13	3.754	4.995	3.364	2.774
14	3.586	4.832	3.560	2.660
15	3.626	4.709	3.392	2.676
16	3.600	4.696	3.264	2.640
17	3.741	4.805	3.299	2.603
18	3.766	4.716	3.277	2.662
19	3.609	4.771	3.277	2.808
20	3.673	4.724	3.244	2.774

- ***EXTRAORAL SCANNING (GROUP ID)- dies stone cast scanning***

Samples	Buccolingual Distance (BL)	Mesiodistal Distance (MD)	Mesio-proximal Distance (MP)	Disto-proximal Distance (DP)
1	3.545	4.632	2.967	2.713
2	3.443	4.612	3.058	2.667
3	3.504	4.592	3.061	2.603
4	3.464	4.639	3.062	2.579
5	3.468	4.658	3.123	2.835
6	3.420	4.647	2.970	2.589
7	3.517	4.843	3.166	2.428
8	3.548	4.591	3.064	2.600
9	3.491	4.570	3.068	2.643
10	3.588	4.632	3.055	2.600
11	3.508	4.669	3.059	2.631
12	3.721	4.527	2.990	2.571
13	3.610	4.712	2.971	2.625
14	3.432	4.627	3.119	2.592
15	3.343	4.552	3.090	2.528
16	3.558	4.629	3.099	2.625
17	3.550	4.715	3.141	2.589
18	3.651	4.622	3.128	2.693
19	3.538	4.691	3.082	2.748
20	3.481	4.618	3.026	2.619

- *INTRAORAL SCANNING (GROUP DD)*

Samples	Buccolingual Distance (BL)	Mesiodistal Distance (MD)	Mesio-proximal Distance (MP)	Disto-proximal Distance (DP)
1	3.17	4.29	2.94	2.50
2	3.24	4.30	2.89	2.56
3	3.25	4.34	2.78	2.49
4	3.20	4.31	2.80	2.51
5	3.24	4.30	2.77	2.48
6	3.18	4.29	2.88	2.50
7	3.27	4.37	2.92	2.43
8	3.13	4.24	2.86	2.52
9	3.34	4.39	2.78	2.51
10	3.29	4.30	2.88	2.57
11	3.16	4.37	2.91	2.58
12	3.21	4.33	2.83	2.45
13	3.24	4.43	2.83	2.54
14	3.12	4.38	2.88	2.48
15	3.17	4.31	2.86	2.47
16	3.16	4.25	2.85	2.49
17	3.23	4.33	2.84	2.46
18	3.20	4.29	2.91	2.56
19	3.16	4.32	2.88	2.56
20	3.20	4.30	2.88	2.53

ANNEXURE III

STATISTICAL ANALYSIS OF DATA

Mean

$$\overline{X} = \frac{\Sigma X}{N}$$

Where :

$\overline{X}$ = the data set mean

$\sum$ = the sum of

X = the scores in the distribution

N = the number of scores in the distribution

Range

$$range = X_{highest} - X_{lowest}$$

Where:

$X_{highest}$ = largest score

X_{lowest} = smallest score

Variance

$$SD^2 = \frac{\Sigma(X - \overline{X})^2}{N}$$

The simplified variance formula

$$SD^2 = \frac{\Sigma X^2 - \frac{(\Sigma X)^2}{N}}{N}$$

Where:

SD^2 = the variance

$\sum$ = the sum of

X = the obtained score

$\overline{X}$ = the mean score of the data

N = the number of scores

Standard Deviation (N)

$$SD = \sqrt{\frac{\Sigma(X - \overline{X})^2}{N}}$$

The simplified standard deviation formula

$$SD = \sqrt{\frac{\Sigma X^2 - \frac{(\Sigma X)^2}{N}}{N}}$$

Where:

SD = the standard deviation

$\sum$ = the sum of

X = the obtained score

$\overline{X}$ = the mean score of the data

N = the number of scores

One Way ANOVA

The formula for the one-way **ANOVA** *F*-test statistic is

$$F = \frac{\text{between-group variability}}{\text{within-group variability}}.$$

The between-group variability" is

$$\sum_{i=1}^{K} n_i(\bar{Y}_{i\cdot} - \bar{Y})^2/(K-1)$$

where Y_i denotes the sample mean in the i^{th} group, n_i is the number of observations in the i^{th} group, $\bar{Y}$ denotes the overall mean of the data, and K denotes the number of groups.

The "within-group variability" is

$$\sum_{i=1}^{K}\sum_{j=1}^{n_i}(Y_{ij} - \bar{Y}_{i\cdot})^2/(N-K),$$

where Y_{ij} is the j^{th} observation in the i^{th} out of K groups and N is the overall sample size.

Independent t-test

Independent t Test can be used to determine if two sets of data are significantly different from each other and is most commonly applied when the test statistic would follow a normal distribution. The independent samples *t*-test is used when two separate sets of independent and identically distributed samples are obtained, one from each of the two populations being compared

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\left(\frac{(N_1-1)s_1^2 + (N_2-1)s_2^2}{N_1 + N_2 - 2}\right)\left(\frac{1}{N_1} + \frac{1}{N_2}\right)}}$$

Where X1 =Mean of the first Group, X2 =Mean of the Second Group

ANNEXURE IV

PLAGIARISM REPORT

Document Information

Analyzed document	THESIS AKANKSHA.docx (D158447451)
Submitted	2/12/2023 5:12:00 PM
Submitted by	Dr. Swati Gupta
Submitter email	drswatigupta30@bbdu.ac.in
Similarity	6%
Analysis address	drswatigupta30.bbduni@analysis.urkund.com

Sources included in the report

W	URL: https://j-ips.org/article.asp?issn=0972-4052;year=2020;volume=20;issue=1;spage=27;epage=37;aul... Fetched: 6/28/2022 7:12:44 PM	3
W	URL: https://www.researchgate.net/publication/323364976_Finish_line_distinctness_and_accuracy_in_7_... Fetched: 7/14/2020 2:13:03 PM	1
W	URL: https://journalimplantdent.springeropen.com/articles/10.1186/s40729-021-00352-9 Fetched: 1/4/2022 5:32:57 AM	2
W	URL: https://bmcoralhealth.biomedcentral.com/articles/10.1186/s12903-017-0383-4 Fetched: 9/30/2019 1:59:16 PM	2
W	URL: https://www.nucleodoconhecimento.com.br/dentistry/digital-workflow Fetched: 11/2/2021 4:14:23 PM	1
W	URL: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5903173/ Fetched: 11/10/2021 4:43:24 PM	5
W	URL: https://bmcoralhealth.biomedcentral.com/articles/10.1186/s12903-020-01278-1 Fetched: 10/20/2020 6:33:05 AM	3
W	URL: https://www.researchgate.net/publication/321750696_Intraoral_scanners_in_dentistry_A_review_of... Fetched: 6/12/2020 5:35:27 AM	4
W	URL: https://www.mdpi.com/2304-6767/10/7/123/pdf Fetched: 1/23/2023 9:40:33 PM	4
W	URL: https://pubmed.ncbi.nlm.nih.gov/33289647/ Fetched: 5/8/2022 9:40:19 PM	1
W	URL: https://journalofosseointegration.eu/jo/article/download/485/319 Fetched: 4/23/2022 11:17:37 AM	2
W	URL: https://www.researchgate.net/publication/280497662_Comparison_of_repeatability_between_intraor... Fetched: 5/13/2022 1:53:33 PM	2
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Swati
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