ASSESSMENT OF ACCURACY AND REPRODUCIBILITY OF INTRA-ORAL SCANNERS AS IMPRESSION TAKING METHOD FOR POST AND CORE

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FACULTY OF DENTISTRY

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ASSESSMENT OF ACCURACY AND REPRODUCIBILITY OF INTRA-ORAL SCANNERS AS IMPRESSION TAKING METHOD FOR POST AND CORE

ABSTRACT

Digital workflows have significantly transformed restorative dental practices by enabling the creation of customized fibre-reinforced posts and zirconia cores (P+C) through CAD/CAM technology. Despite the reduced necessity for posts due to advancements in adhesive dentistry, they remain essential for restoring extensively damaged teeth. Prefabricated fibre posts often fail to conform accurately to post-space shapes, raising questions about the precision of intraoral scanners (IOS) in fabricating custom posts compared to traditional silicone impressions. This study aims to compare the accuracy and reproducibility of two intraoral scanners (IOS) namely Trios 5 and Primescan as well as the combination technique of the traditional silicone impression and digital scanner against traditional silicone impression techniques in recording post-space depths in extracted teeth. The significance of the study is to understand the precision of IOS versus traditional methods is crucial for ensuring optimal fit and function of custom posts, thereby improving clinical outcomes and patient satisfaction in restorative dentistry. A total of 42 extracted teeth were categorized into seven groups based on tooth type: mandibular lateral incisors, maxillary central incisors, maxillary canines, maxillary first premolars, mandibular second premolars, maxillary first molars, and mandibular first molars. For each tooth, five impressions were taken using different techniques: traditional polyvinyl siloxane (PVS), Trios 5 intraoral scanner (IOS), Primescan IOS, and combination techniques where PVS impressions were scanned with both Trios 5 and Primescan. Post-space depths were measured with a K-file and compared to measurements obtained from the three methods (PVS, Trios 5, and Primescan). Traditional impressions were measured with digital calipers, and Standard Tessellation

Language (STL) files from IOS were analysed using Exoviewer3D 2.4 software. Reproducibility was assessed by superimposing digital impressions (Trios 5 and Primescan) and the combination technique impressions (PVS-Trios 5 and PVS-Primescan). Data were analysed using pairwise comparison, Kruskal Wallis and Mann-Whitney U tests. The study revealed significant differences in the accuracy of post-space depth recordings among the different methods. Traditional silicone impressions demonstrated higher accuracy and reproducibility than digital impressions obtained directly from IOS. The combination technique, which involved scanning traditional silicone impressions with IOS, showed improved performance over direct digital impressions, particularly in recording the full depth of the post spaces and reproducibility of the impressions. While digital impressions via intraoral scanners offer advancements in speed and convenience, traditional silicone impressions remain the gold standard for accuracy in post-space depth recording. The combination of traditional and digital techniques provides a viable alternative, enhancing the precision of custom post fabrication. These findings underscore the need for further refinement in IOS technology to match the reliability of traditional methods, ensuring better clinical outcomes in restorative dentistry.

Keywords: Intraoral Scanners, Restorative Dentistry, Digital Impressions, Post-Space Depth

PENILAIAN KETEPATAN DAN KEBOLEHULANGAN PENGIMBAS INTRA-ORAL DALAM KAEDAH PENGAMBILAN CETAKAN UNTUK TIANG DAN TERAS

ABSTRAK

Aliran kerja digital telah secara signifikan mengubah praktik pergigian restoratif dengan memungkinkan pembuatan pos serat yang diperkuat dan teras zirkonia (P+C) yang disesuaikan melalui teknologi CAD/CAM. Walaupun keperluan untuk tiang telah berkurang kerana kemajuan dalam pergigian pelekat, ia tetap penting untuk memulihkan gigi yang rosak secara meluas. Tiang serat prafabrikasi sering gagal menyesuaikan dengan tepat kepada bentuk ruang kanal, menimbulkan persoalan mengenai ketepatan pengimbas intraoral (IOS) dalam membuat tiang khusus berbanding dengan kesan silikon tradisional. Kajian ini bertujuan untuk membandingkan ketepatan dan kebolehulangan dua pengimbas intraoral (IOS) iaitu Trios 5 dan Primescan serta teknik gabungan kaedah cetakan silikon tradisional dan pengimbas digital berbanding teknik cetakan silikon tradisional dalam merekodkan kedalaman ruang kanal pada gigi yang diekstrak. Kepentingan kajian ini adalah untuk memahami ketepatan IOS berbanding dengan kaedah tradisional yang penting untuk memastikan kesesuaian dan fungsi tiang khusus yang optimum, dengan itu meningkatkan hasil klinikal dan kepuasan pesakit dalam pergigian restoratif. Sebanyak 42 gigi yang diekstrak dikategorikan ke dalam tujuh kumpulan berdasarkan jenis gigi: insisor lateral mandibula, insisor tengah maksila, kanin maksila, premolar pertama maksila, premolar kedua mandibula, molar pertama maksila, dan molar pertama mandibula. Lima cetakan diambil untuk setiap gigi menggunakan *polyvinyl siloxane* (PVS) konvensional, Trios 5 IOS, Primescan IOS, dan teknik gabungan di mana cetakan PVS diimbas dengan kedua-dua Trios 5 dan Primescan. Kedalaman ruang kanal yang diukur dengan K file dibandingkan dengan pengukuran dari tiga kaedah (PVS, Trios 5 dan Primescan). Cetakan konvensional diukur dengan caliper digital, dan fail STL dari IOS dianalisis menggunakan perisian Exoviewer3D 2.4. Sampel juga dibandingkan untuk kebolehulangan di mana cetakan digital disuperimpose (Trios 5 dan Primescan) dan cetakan teknik gabungan (PVS-Trios 5 dan PVS-Primescan). Data dibandingkan menggunakan perbandingan berpasangan, Ujian Kruskal Wallis dan Ujian Mann-Whitney U. Kajian ini menunjukkan perbezaan ketara dalam ketepatan rakaman kedalaman ruang kanal antara kaedah yang berbeza. Cetakan silikon tradisional menunjukkan ketepatan dan kebolehulangan yang lebih tinggi berbanding dengan cetakan digital yang diperoleh secara langsung daripada IOS. Teknik gabungan, yang melibatkan pengimbasan cetakan silikon tradisional dengan IOS, menunjukkan prestasi yang lebih baik berbanding dengan cetakan digital langsung, terutamanya dalam merekodkan kedalaman penuh ruang tiang. Walaupun cetakan digital melalui pengimbas intraoral menawarkan kemajuan dalam kelajuan dan kemudahan, cetakan silikon tradisional tetap menjadi piawaian emas untuk ketepatan dalam merekodkan kedalaman ruang pos. Gabungan teknik tradisional dan digital menyediakan alternatif yang boleh diterima, meningkatkan ketepatan pembuatan tiang khusus. Penemuan ini menekankan keperluan untuk penambahbaikan lanjut dalam teknologi IOS untuk menyamai kebolehpercayaan kaedah tradisional, memastikan hasil klinikal yang lebih baik dalam pergigian restoratif.

Kata kunci: Pengimbas Intraoral, Pergigian Restoratif, Cetakan Digital, Kedalaman Ruang Tiang.

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LIST OF SYMBOLS AND ABBREVATIONS

IOS	**: Intraoral Scanner**
CAD/CAM	**: Computer-aided design/computer-aided manufacturing**
P+C	**: Post and core**
PVS	**: Polyvinyl siloxane**
STL	**: Standard Tessellation Language**
AI	**: Artificial Intelligence**

LIST OF APPENDICES

CHAPTER 1: INTRODUCTION

1.4 Introduction

Post and core (P+C) restorations are frequently employed to restore teeth that have undergone endodontic treatment and exhibit substantial coronal structure loss ("The Glossary of Prosthodontic Terms: Ninth Edition," 2017).

With the advances in adhesive technology, dentistry today avoids the use of P+C, but when clinical situations where there is insufficient tooth structure, P+C is still in use as a resort to anchor restoration especially in the anterior aesthetic region (Naumann et al., 2018; Zarow et al., 2018). In these situations, the post provides retention and resistance form to the core and tooth respectively (Perdigão et al., 2007).

Post-core systems can be classified into two basic types: one-piece cast post-core systems and two elements systems comprising a prefabricated post with a composite core.

Since the introduction and the wide availability of prefabricated post systems, this has been the go-to for most dentists. The most common prefabricated post system used is the glass-fibre-reinforced post system. This has been a preferred system as they have high aesthetics and more importantly share a similar elasticity modulus to dentine which would reduce the risk of root fractures (Basaran et al., 2019).

However, one of the main issues with the pre-fabricated post system is the discrepancy between prefabricated post shape and post space shape (Gomes et al., 2014; Perdigão et al., 2007).This discrepancy affects the uneven cement distribution in the canal producing uneven stress to the dentine of the tooth.

In recent years, custom post systems such as customised glass-fibre-reinforced posts and customised zirconia posts have emerged thanks to digital dentistry. There has been a transformative paradigm shift in the dental field with the development of computer-aided design/computer-aided manufacturing (CAD/CAM) technology and the advances in intraoral scanners (IOS).

Most clinical setups and as many as 40-50 % of dentists globally are using the digital restorative workflow (Al-Hassiny, 2023). This number will only continue to rise. We have come so far forward in dentistry that we can now manufacture customized fibre-reinforced and zirconia posts and core (P+C) in a fully digital workflow with precision and speed (Perlea et al., 2023; X Guo, 2023).

Though this can be done digitally, silicone impressions using polyvinylsiloxane (PVS) is still the gold standard for post and core impressions (Dupagne et al., 2023). Despite the advancement of technology, the accuracy of the IOS to obtain a digital impression to form custom posts using CAD/CAM is still questionable (Comba et al., 2021).

The accuracy of the usage of intraoral scanners for impressions for fixed prosthodontics such as crowns, bridges, and veneers has been studied time and again. Seelbach et al. (2013) concluded that digital impressions for fixed prosthetic restorations have a comparable accuracy to traditional impressions.

However, when it comes to post impressions, the main problem faced is the recording of the depth of the narrow-confined post length. The early IOS generations were proven to be unreliable when used for recording the impression of a post-space (Comba et al., 2021).

A study was done with the TRIOS 3 on premolars by (Pinto, 2017) revealed that there are depth limitation readings, especially in narrow root channels. This is due to the light beam not reaching deeper levels.

However, a few years later, (Elter et al., 2022) concluded that Primescan

(Dentsply Sirona, Charlotte, North Carolina, USA) could be used for digital impressions if the post depth does not exceed 14mm with more or equal to 2.2 mm diameter. (Emam et al., 2023) then proved in his paper that the Medit i500 (Medit Corporation, Seoul, South Korea) scanner showed the highest post-space digital trueness as compared to Primescan. Hence, with time newer generation scans showed minimal significant difference in the measurement error of impressions on post and core preparations (X Guo, 2023).

Although previous studies evaluated the accuracy of IOS and compared them to traditional silicone impressions, most of these studies were either carried out on only bicuspid premolars (Emam et al., 2023; X Guo, 2023), maxillary incisors (Emam et al., 2023), mandibular canine (Elter et al., 2022) or 3D-printed models (Dupagne et al., 2023).

A study was conducted before this to validate intraoral scanners (IOS) across 12 different brands, the IOS devices were assessed using four distinct methods: (a) a summary chart, (b) a comparative assessment, (c) data based on in vitro measurements, and (d) accuracy measurements. A scoring system was established to provide an objective rating of each IOS. According to this evaluation, Primescan emerged as the top performer, followed closely by Trios 4 (Roth et al., 2022).

The TRIOS 5 (3shape, Copenhagen, Denmark) was launched at the end of 2022. 3Shape had claimed that the TRIOS 5 is 30% smaller as compared to the TRIOS 4. No literature was found to compare the accuracy and the scanning efficiency of this new scanner. Additionally, no literature comparing the accuracy with more recent IOS such as Trios 5 and Primescan IOS scanners to measure post depth.

Before converting to a fully digitalised workflow for post impressions we should understand that inaccurate digital scans may contribute to clinically relevant discrepancies between the tooth and definitive restoration. Clinicians should be aware that the accuracy of digital scans varies, depending on the tooth preparation and type of IOS used (Park et al., 2020).

1.5 Aim of study

The aim of this study is to compare the accuracy of representative intra-oral scanners in obtaining a digital impression against traditional silicone techniques in terms of depth of field and reproducibility on extracted teeth.

1.3 Objectives

The objectives of this study are:

(i) To compare the accuracy of depth of post-space reading using intra-oral scanners (Trios 5 and Primescan) against traditional silicone.

(ii) To determine the reproducibility of anatomic post-space readings using intra-oral scanners (Trios 5 and Primescan) against combination of traditional silicone technique and intraoral scanner.

1.4 Null Hypothesis

The null hypotheses for this study are:

(a) There is no significant difference among the impression methods used in the accuracy of post-space length.

(b) The anatomy of the post space is reproducible with all impression methods.

CHAPTER 2: LITERATURE REVIEW

2.1 Post and core (P+C)

For over 250 years, posts have been used in dental restorations. Initially, in 1728, Pierre Fauchard described metal posts called "tenons" for retaining bridges. By the mid-1800s, wooden posts replaced metal, but they often caused root fractures by absorbing fluids and expanding. The late 19th century saw the introduction of the "Richmond crown," a post-retained crown with porcelain facing, designed as a bridge retainer. In the 1930s, the custom cast post-and-core method was developed, improving marginal adaptation and allowing for variation in the crown's insertion path (Terry & Swift, 2010).

Ideally, a post and core system should facilitate crown retention. It should be biocompatible, non-toxic, and exhibit high tensile strength and fatigue resistance to endure occlusal and shear forces.

The retention of the post is a critical factor that influences the longevity and success of the final restoration. Several factors affect post retention and stability, including post length, shape, diameter and surface texture, and the type of cement used (Hatem et al., 2022).

The post must distribute forces uniformly to the surrounding root surface and extend apically to a length equivalent to at least the height of the crown or two-thirds of the root length. This configuration ensures equal stress distribution and enhances resistance to occlusal loads (Al-Qarni, 2022).

The optimal post should exhibit mechanical properties similar to those of dentine and should be bonded with a thin, uniform, and bubble-free layer of cement to improve the durability of the post-endodontic restoration. A cement layer thickness ranging from 250 to 500 µm is deemed acceptable (Prado et al., 2016).

Today, there are many different post-core systems currently available on the market, and they vary in terms of post type, material, design, surface texture, and fit (Lee et al., 2017).

2.1.1 Pre-fabricated post system

Traditional prefabricated metal post systems have been associated with a high incidence of root fractures. Non-metallic prefabricated posts, such as ceramic (white zirconium oxide) and fibre-reinforced resin posts, have been developed to address this issue.

Zirconium oxide posts offer high flexural strength, biocompatibility, and corrosion resistance but are difficult to cut and remove intraorally during retreatment.

In contrast, fibre-reinforced composite resin post-and-core systems provide several advantages. It allows for completion in one visit, eliminates laboratory fees, does not corrode over time, minimizes the chance of root fractures, and preserves more of the natural tooth. Additionally, it does not negatively impact aesthetics.

However, fibre posts, being prefabricated, cannot precisely conform to the shape of the root canal and are often associated with debonding issues (Cheleux & Sharrock, 2009). In terms of accuracy, it is reduced when compared to customised post systems (Al-Qarni, 2022).

2.1.2 Customised post system

Traditionally custom-cast metal post provides excellent geometric adaptation to flared or elliptical root canals and require minimal tooth structure removal. They are particularly suited for canals with extreme taper, noncircular cross-sections, irregular shapes, and limited coronal tooth structure. Cast metals are stiffer than dentine. The high modulus of elasticity of the alloy used can create stress concentrations in the root, leading to post separation and failure. Additionally, the transmission of occlusal forces through the metal core can cause root fractures (Terry & Swift, 2010). The rigidity of metal posts contributes to higher stress transmission, leading to more root fractures (Fokkinga et al., 2004). Additionally, cast metallic posts may result in gingival discolouration and shadowing of the tooth's cervical aspect. Hence, the use of cast metal posts has declined tremendously.

Although traditional cast posts and cores were once considered the standard, but an increasing patient demand for enhanced aesthetics prompted the development of ceramic alternatives. This evolution led to the introduction of castable glass ceramics and glass-infiltrated ceramics. Notably, zirconia posts emerged in 1995 as a viable alternative to cast metal posts and cores, particularly advantageous for cases involving extensive loss of coronal structures. Zirconia posts offered superior aesthetics due to their high translucency and colour-matching capabilities, resulting in restorations closely resembling natural teeth.

With the development of CAD/CAM technology, customised zirconia or fibre post became possible.

2.2 CAD/CAM in dentistry

The application of CAD/CAM technology has significantly improved the design and production of dental restorations, including crowns, crown lays, veneers, inlays, onlays, fixed bridges, dental implant restorations, removable and fixed dentures and orthodontic appliances. Originally developed in the 1960s for the automotive and aerospace industries, CAD/CAM technology was introduced to dentistry in the 1980s (Goodacre et al., 2012). Today, it is widely utilized in almost every aspect of dental practice

CAD/CAM technology utilizes either “additive” or “subtractive” manufacturing methods. Computer-Aided Design (CAD) involves the creation of digital 3D models for dental products, whereas Computer-Aided Manufacturing (CAM) includes software-controlled techniques such as CNC milling and 3D printing. Together, CAD and CAM streamline the production process for various dental restorations and prostheses, facilitating the efficient manufacturing of crowns, dentures, inlays, onlays, bridges, veneers, implants, and abutment restorations. This also gives an opportunity to dentists to fabricate customised posts and cores (P+C) in a fully digital workflow (Leven et al., 2022).

The adoption of CAD/CAM technologies has transformed dental practices and laboratories by digitizing processes that were previously manual. Traditional methods required dental impressions with alginate or silicone, leading to the creation of plaster models and necessitating multiple patient visits. Modern CAD/CAM dentistry replaces these steps with digital impressions captured by intraoral 3D scanners, which can be directly utilized for CAD design and CAM manufacturing, thereby significantly streamlining the workflow.

CAD/CAM dentistry marks a significant advancement over traditional methods, offering enhanced speed, cost-effectiveness, patient convenience, and superior product quality. These technologies continue to improve the efficiency and capabilities of dental practices and laboratories.

The CAD/CAM technology has been considered for the fabrication of custom-cast post and core. The use of CAD/CAM technology in the post and core fabrication was first elaborated in 2007 by Awad and Marghalani and later by Strecker and Geissberger. This was followed by multiple in vitro studies and case reports utilizing various techniques and materials.

2.3 Intraoral Scanners (IOS)

2.3.1 History

Francois Duret, in France, pioneered optical impressions in 1971. The concept of intraoral scanning for dental application was introduced by Durethas in 1973 (Martin et al., 2015). In the early 1980s, Professor Werner H. Mormann, together with Italian engineer Marco Brandestini, were the first to patent and design an intraoral scanner, giving rise to the first generation of Chairside CEREC ® marketed by Siemens and tested this technology directly in the dental office(Mhatre et al.). They used an intraoral camera to digitize the teeth and oral tissues, to then perform the design and subsequent machining using a milling machine. This system was very innovative at that time, making restorations in a single visit.

2.3.2 Scanning technology

An intraoral scanner includes software, hardware (a handheld camera), and a computer (Richert et al., 2017). Key considerations in selecting a system include data acquisition speed, measurement accuracy, and resolution. The scanning field size should range from 14x14mm to 25x14mm, with a scanning depth of at least 10mm but not exceeding 14mm to avoid unclear images or fogging. Furthermore, the scanner resolution should be a minimum of 25µm(Susic et al., 2017).

Parts of the intraoral scanning system (Abad Coronel et al., 2017):

- Machine Handling The Movement Of The Probe
- Measurement Probe
- Control Or Computing System
- Measurement Software

The scanner types available according to emission used are (Mhatre et al.):

Table 2.1 explains different types of scanners and the type of emission technology used.

Table 2. 1 Scanner types according to emission used

Intraoral Scanner	Emission Used
Three-dimensional laser scanners	It emits a laser beam and detects its return.
Optical scanner	This type of scanner projects white light or a laser source. The light source and the receiving unit are positioned at a specific angle to each other.
Mechanical scanner	A gypsum model is created using traditional printing techniques and then scanned. The master model is read mechanically line by line, with the structure measured using a ruby ball.
Photographic technology scanners	The field of view for this type of scanner is cone-shaped, which limits its ability to capture information from hidden surfaces. It records individual images of the dentition.
Video technology scanners	The most commonly used digital format in intraoral scanning is the Open Standard Tessellation Language (STL). This format captures scanned areas

	through sequential high-speed shots, functioning similarly to a video camera.

There are many types of scanners available in the market. The scanners available in the market are (Abad Coronel et al., 2017) shown in Table 2.2.

Table 2. 2: Scanners available in the market

Scanner Name	Manufacturer	Image Caption	Powder use
CEREC Bluecam	Sirona	Photo	Cerec Optispray
CEREC Omnicam	Dentsply Sirona	Video	No
Primescan	Dentsply Sirona	Video	No
Trios	3Shape	Video	No
Sistema LaVa C.O.S	3M ESPE	Video	No
Sistema iTero	Cadent/Straumann	Video	No
Sistema E4D	Technologias D4D	Video	No
Zfx Intrascan	MHT technologies Zimmer	Photo	No
CondorScan	Biotech Dental	Video	No
PIC dental	PIC DENTAL	Photogrammetry	No
Dental WIngs	Straumann	Video	
Wow	Biotech Dental	Video	No
Medit 500	Dent Core	Video-photogrammetry	No

2.4 Impression methods

2.4.1 Traditional method

Impressions for post space to fabricate custom posts using the traditional method have been considered the gold standard (Piangsuk et al., 2023), can be achieved through either direct or indirect techniques.

Direct pattern fabrication involves modelling the root canal using an acrylic resin pattern within the canal space. In contrast, indirect pattern fabrication involves creating a stone cast from an elastomeric impression namely polyvinylsiloxane (PVS).

The limitations of both direct and indirect pattern fabrication techniques include the polymerization shrinkage of the acrylic resin pattern, dimensional changes in gypsum products, technique sensitivity, the risk of residual resin debris within the canal, and the associated costs of clinical and laboratory labour (Falcao Spina et al., 2018).

Traditional impression techniques, such as using polyether or polyvinyl siloxane materials, are often cited for their high accuracy in capturing fine details necessary for post impressions. Studies have found that these materials provide excellent marginal fit and adaptation accuracy (Fokkinga et al., 2004).

2.4.2 Digital impression

CAD CAM-customized zirconia or fibre glass post-and-core has been fabricated by scanning a resin post pattern with an extraoral scanner. This can also be done by scanning the post space directly with an intraoral scanner.

2.4.2.1 Intraoral scanner (IOS)

2.4.2.1.1 Trios (3Shape)

In December 2010, the TRIOS™ intraoral scanner was launched by 3Shape (Copenhagen, Denmark). This powder-free intraoral scanner operates using continuous confocal imaging. It employs structured light projected onto the tooth through interference fringes, with mechanical oscillation of the light combined with variations in the confocal plane. The resulting signal is captured by video-photometry using a charge-coupled device sensor, enabling rapid scanning. In September 2022, 3Shape officially released the TRIOS 5 during an online event.

2.4.2.1.2 Primescan (Dentsply Sirona)

CEREC PrimeScan is the latest evolution of the IOS of this manufacturer which contains a touch panel and screen, with the all new CEREC 5 software and has been available in the market since 2019. With a higher scanning speed, the processor of the scanner can process up to 10,00,000 of 3D points per second. To make the impressions of the sulcus in sub-gingival preparations or post-extraction sockets feasible, Depth of scanning should be up to 20 mm.

2.4.3 Combination method

Scanning the elastomeric impression directly could eliminate the fabrication of the resin pattern in both the direct and indirect techniques of post impression and improve the accuracy of the post, conserve time, and be cost-effective.

2.5 Accuracy of IOS in scanning depth

The accuracy of intraoral scanners (IOS) in capturing the depth of scanned spaces is a critical factor in the precise adaptation of customized post systems. In 2019, the CEREC Company announced that the Primescan scanner could accurately scan deep spaces up to 20 mm (*Primescan*). However, the ability of different scanners to reliably measure post-space depth remains an area requiring further investigation.

A perfect impression is essential for the precise adaptation of customized post systems, as any inaccuracies in the depth measurement can lead to poor fit and compromised outcomes (Emam et al., 2023). The term "precision" is defined as the ability of a measurement to be consistently reproduced, highlighting the importance of repeatability in scanning procedures (Nedelcu et al., 2018). Trueness, on the other hand, is defined as the ability of a measurement to match the actual value (Nedelcu et al., 2018). While precision and trueness are independent parameters, each can be assessed separately, and together they provide a comprehensive evaluation of the accuracy of IOS.

Several factors influence the trueness and precision of intraoral scanners. The pattern in which the scanner is moved over the object affects the accuracy of the scan. Consistent and systematic scan patterns are essential for capturing all necessary details accurately. The material properties, surface texture, and reflectivity of the scanned object can impact the scanner's ability to capture accurate measurements. Different materials may reflect light differently, affecting the scanner's readings. Distance Between the Scanner and the Object: The optimal scanning distance, as recommended by the manufacturer, must be maintained to ensure accurate measurements. Deviations from this distance can result in distortions and inaccuracies. The dimensions of the scanner head and the lightbox can also affect the ability to capture fine details, especially in confined spaces. A smaller scanner head may be advantageous for accessing and accurately scanning deep or narrow post spaces. (Roth et al., 2022) (Alkadi, 2023).

CHAPTER 3: MATERIALS AND METHODS

This study was conducted to compare the accuracy of depth and the reproducibility of post-space reading between two different intraoral scanners namely the Trios 5 and the Primescan as well as comparing it with the traditional silicone technique and the combination of traditional silicone technique and intraoral scanner.

3.1 Materials and Instruments

3.1.1 Root canal treatment

3.1.1.1 Materials used for root canal treatment

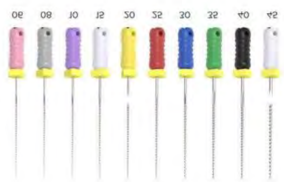
Table 3. 1: Materials used for root canal treatment

Product Name	Image	Main Chemical composition	Manufacturer
AH Plus Sealer		Epoxy-Amine - Resin	Dentsply De Trey, Konstanz, Germany.
ProTaper Next Gutta Percha		Gutta-percha and zinc oxide	Dentsply Tulsa Dental Specialties, Tulsa, OK, USA
ProTaper Next Paper Points		Cellulose material	Dentsply Tulsa Dental Specialties, Tulsa, OK, USA

Intermediate Restorative Material (IRM)		Zinc Oxide Eugenol	Dentsply Caulk, Milford, Del
RC Prep		EDTA (Ethylene Diamine tetra acetic acid)	Premier Dental, Philadelphia, PA, U.S. A

3.1.1.2 Instruments used for root canal treatment

Table 3. 2: Instruments used for root canal treatment

Product Name	Image	Manufacturer
K files		Dentsply Maillefer, Baillagues, Switzerland

ProTaper Next Files		Dentsply Tulsa Dental Specialties, Tulsa, OK, USA

3.1.2 Instrument for post-space preparation

Table 3. 3: Instrument used for post-space preparation

Product Name	Image	Manufacturer
3M RelyX Fibre Post Drill Size 2 (Red)		3M ESPE, Germany

3.1.3 Material used for Impression

Table 3. 4: Material used for Impression

Product Name	Image	Main Chemical Composition	Manufacturer

Light Body Polyvinyl Siloxane		addition silicone	Dentsply Sirona, Charlotte, North Carolina, U.S. A

3.2 Intra-oral scanners used for impression

Table 3. 5: Intra-oral scanners used for impression

IOS	Manufacturer	Scanner technology	Light Source	Acquisition method
Trios 5 	3Shape, Copenhagen, Denmark	Confocal Microscopy	Light	Video Sequencing
Primescan 	Dentsply Sirona, Charlotte, North Carolina, U.S. A	Optical high-frequency contrast analysis:	Light	Video Sequencing

		a combination of confocal microscopy and fringe light projection		

3.3 Methodology

The research methodology of this study was subdivided into seven distinct components, drawing upon methods from two key sources: Alkhalidi et al. (2022) and Pinto et al. (2017). The subdivisions are as follows:

- Sample Size Calculation
- Teeth Selection
- Tooth Preparation
- Post Space Preparation
- Fabrication of mount blocks
- Impression Taking
- Data Collection and Investigation

3.3.1 Sample size calculation

A prior power analysis was conducted using measurement values from a previous study by Pinto et al. (2017), which compared the Trios (3Shape) and traditional silicone impression techniques. The sample size calculation was performed using G*Power 3.1.9.7, with a significance level (α) of 0.05 and a power of 80% ($1 - \beta = 0.80$). The analysis determined that a minimum group sample size of 20 was necessary (power=0.80; effect size=1.40).

In contrast to the Pinto et al. (2017) study, which examined only one type of tooth, this study involves seven different types of teeth. Therefore, the reference sample size from Pinto et al.'s study, which included six teeth of the same type, was used as a reference. Hence in this study six teeth of each type of teeth were used and resulting in a total of 42 samples used.

3.3.2 Teeth Selection

Human extracted teeth were collected for this study from multiple private dental clinics. The teeth were stored in distilled water at room temperature. Then teeth suitable for this study were meticulously chosen according to the inclusion and exclusion criteria of this study. To ensure the integrity and reliability of the results, a stringent set of exclusion criteria was applied. Teeth exhibiting any signs of cracks, caries, restorations, or previous root canal treatments were excluded from the sample. Additionally, teeth with evidence of root resorption, or those containing posts or crowns, were also excluded. This rigorous selection process was essential to ensure that the teeth used in the study were free from any pre-existing conditions that could potentially confound the results, thereby ensuring the accuracy and validity of the experimental outcomes.

Teeth that were chosen were:

- 6 maxillary central incisors
- 6 mandibular lateral incisors
- 6 maxillary canines,
- 6 maxillary first premolars

- 6 maxillary first molars
- 6 mandibular first premolars
- 6 mandibular first molars

Detailed photographic documentation was conducted to capture bucco-lingual and mesio-distal views of each tooth. Additionally, periapical radiographs were taken from two specific projections: mesio-distal and vestibular-lingual. These radiographs were obtained to provide a comprehensive baseline assessment.

After completing the root canal treatment and post-space preparation, vestibular-lingual projection radiographs were taken.

3.2.3 Teeth preparation

During the preparation of the specimens, all teeth underwent thorough cleaning using an ultrasonic scaler (Acteon ®, France) to ensure the removal of any surface debris and contaminants. This step was crucial for providing a clean working surface and facilitating accurate measurements and assessments.

Subsequently, the crowns of each tooth were carefully sectioned 3mm above the cemento-enamel junction. This procedure was performed using a diamond disc mounted on a slow-speed handpiece, with constant water cooling to prevent overheating and damage to the dental tissues. The precise sectioning above cemento-enamel junction allowed for a standardized starting point for the subsequent measurement of depth.

The working lengths of all the root canals were determined using a #10 K-file (Dentsply, Maillefer, Switzerland). The file was gently inserted into the root canals until its tip became just visible at the apical foramen, as observed under dental loupes (UNIVET®, Italy) with 3.0x magnification.

The working length for each canal was then established as 1 mm short of this measured length,

Root canal preparation was performed using ProTaper Next ® rotary files (Dentsply Tulsa Dental Specialties, Tulsa, OK, USA).All canals were enlarged to size X2, except for the maxillary central incisor, maxillary canine, and palatal root of the maxillary molar, which were enlarged to size X3 together with a RC prep, 15% EDTA gel (Premier Dental, Philadelphia, PA, USA). This was followed by irrigation with 2 ml of distilled water and then 2 ml of 5.25% sodium hypochlorite., all canals were subsequently rinsed with 10 ml of distilled water.

Drying of the canals was achieved using ProTaper Next ® paper points (Dentsply Tulsa Dental Specialties, Tulsa, OK, USA) corresponding to the size of the preparation. The canals were obturated with a single gutta-percha cone matched to the canal's preparation size, conforming to working length with a slight resistance (tugback) effect. AH-Plus (Dentsply De Trey, Konstanz, Germany.), root canal resin sealer was used in conjunction with the gutta-percha cone. Excess gutta-percha was removed and condensed vertically with a hand plugger until 2 mm below the cemento-enamel junction (CEJ).

Following obturation, a cotton pellet was placed in the canal, and the opening was sealed with Intermediate Restorative Material (IRM) (Dentsply Sirona, Charlotte, North Carolina, USA). The specimens were then stored in an incubator (Memmert, Germany) at 37°C with 100% humidity for one week to allow for proper setting and sealing of the materials.

3.2.4 Post-space preparation

After one week of incubation, the temporary filling material was carefully removed from each tooth. Subsequently, the post spaces were prepared using the 3M RelyX Fibre Post Drill size 2 (Red) (3M ESPE, Germany).

Only one canal per tooth was used for post-space preparation. In teeth with multiple canals, the straightest canal was chosen for post placement and prepared accordingly.

Additionally, all six teeth within each group were prepared to the same depth. To ensure consistency, the depth was measured from the most coronal part of the tooth after sectioning which is 3mm above the CEJ. This standardisation was critical to ensure uniformity in the post-space preparation, enabling a consistent evaluation of the outcomes.

The table below shows the canal used for post-space preparation and the depth of preparation for each group.

Table 3.6: Type of teeth with canal prepared and depth (mm)

Teeth	Canal Prepared	Depth (mm)
Maxillary Central Incisor	Single canal	10
Mandibular Lateral Incisor	Single canal	9
Maxillary Canine	Single canal	14
Maxillary First Premolar	Palatal canal	10
Mandibular Second Premolar	Single canal	11
Mandibular First Molar	Palatal	10.5
Mandibular First Molar	Distal	10

3.2.5 Fabrication of mount blocks

To replicate the clinical situation, mounting blocks were created for each group of teeth, resulting in a total of seven distinct blocks. Each block consisted of two teeth positioned to mimic the arrangement of adjacent teeth in the oral cavity, ensuring consistent positioning throughout the study. The selection of teeth for mounting was based on the type of tooth that would naturally be adjacent to the tooth being scanned.

The central area of each block was left open to allow for the interchange of samples within that particular group type. This design facilitated the standardization of scanning conditions across different samples while maintaining the anatomical relationship between adjacent teeth.

The blocks were fabricated using plaster of Paris and poured into a mould to ensure precise and stable positioning of the teeth. This method provided a durable and consistent framework for the experimental procedures, enhancing the accuracy and reliability of the study's results.

Below is a schematic sample and one example of the block made.

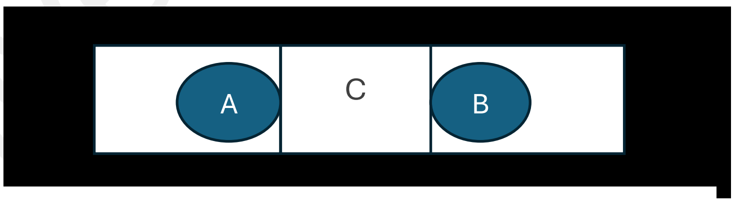


Figure 3. 1 Schematic diagram of mounting block

A-Adjacent tooth mounted

B- Adjacent tooth mounted

C- Free space for change of sample tooth

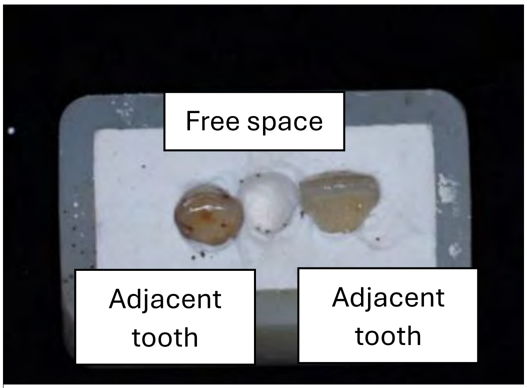


Figure 3. 2 Sample of mounting block

3.2.6 Impression taking

Impression of each sample tooth is taken by inter changing the tooth mounted in the middle of the block. For each sample tooth below are the techniques used:

- One scan impression taken with Trios 5
- One scan impression taken with Primescan
- One impression taken with light body polyvinyl siloxane
- One scan impression of the light body polyvinyl siloxane taken with Trios 5
- One scan impression of the light body polyvinyl siloxane taken with Primescan

In total, one sample tooth produced five different impressions. All impressions were taken by the same operator who was trained for the impression taking by the suppliers of each company.

In terms of calibration, Trios 5 is a calibration-free scanner while Primescan camera and colour were calibrated before use.

3.2.6.1 Digital Impressions

Digital impressions were obtained using the Trios 5 and Primescan intraoral scanners. The scanner distance was set at 4 mm, achieved by mounting the sample tooth 4 mm below the adjacent teeth (Figure 3.3).

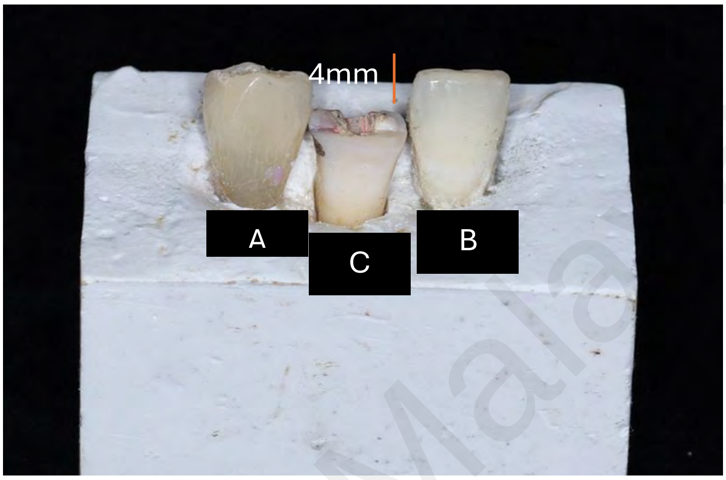


Figure 3. 3 Mounting to standardize scanning

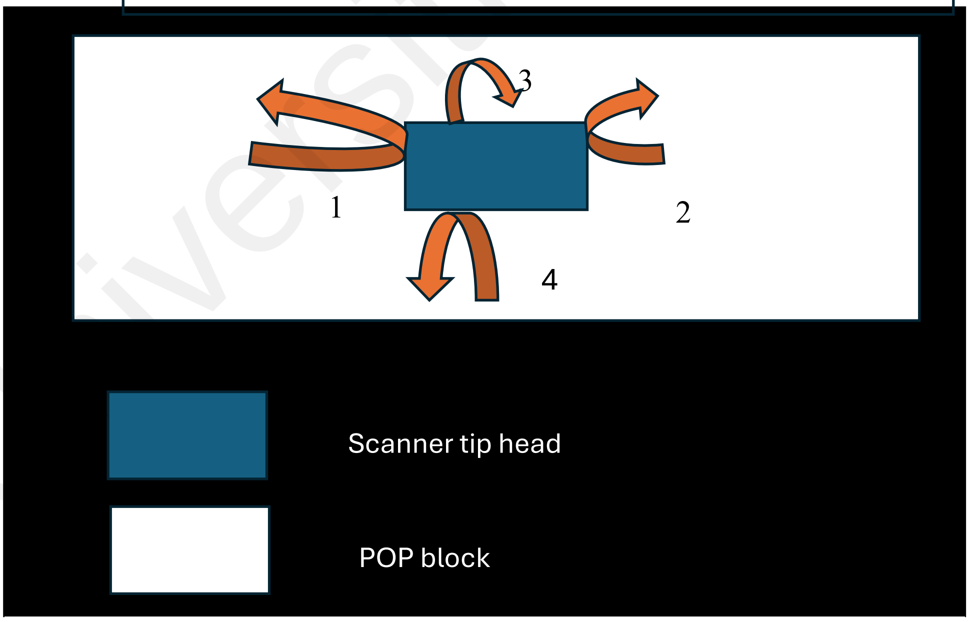


Figure 3. 4 Scanning sequence

The scanner head was positioned on the adjacent teeth to maintain the 4 mm distance (Figure 3.5), and each sample was scanned twice following the same sequence (Figure 3.4).

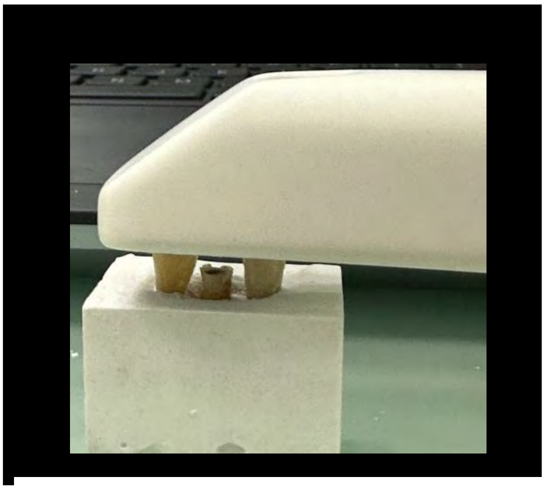


Figure 3.5 Scanning head placement

A Standard Tessellation Language (STL) file was generated for each scan. 42 STL files were obtained for each of the Trios 5 and Primescan techniques. The data was named and saved into a pen drive.

3.2.6.2 Traditional PVS impression

The traditional impression technique employed in this study utilized light body polyvinyl siloxane (PVS) (Dentsply Sirona, Charlotte, North Carolina, U.S.A) to capture the post-space details accurately. To facilitate the removal of the impression material after setting, a paper clip was used as the core. The paper clip was carefully selected and inserted into the post space.

The light body PVS was then meticulously applied into the post space. The application process involved gradually filling the space to ensure complete coverage and to minimize the introduction of air bubbles or voids, which could compromise the accuracy of the impression.

Following the application of the PVS, the paper clip was inserted carefully into the filled post space, ensuring that it was fully embedded in the PVS (Figure 3.6).

The PVS was allowed to harden completely, a critical step to ensure that the material captured the fine details of the post space accurately. The setting time of the PVS was observed meticulously, adhering to the manufacturer's recommendations to ensure optimal hardening and accuracy of the impression.

Once the PVS had fully set, the impression was carefully removed from the post space by pulling from the free end of the paper clip. This removal process was conducted with care to avoid any deformation or distortion of the impression, thus preserving the detailed replication of the post space (Figure 3.7).

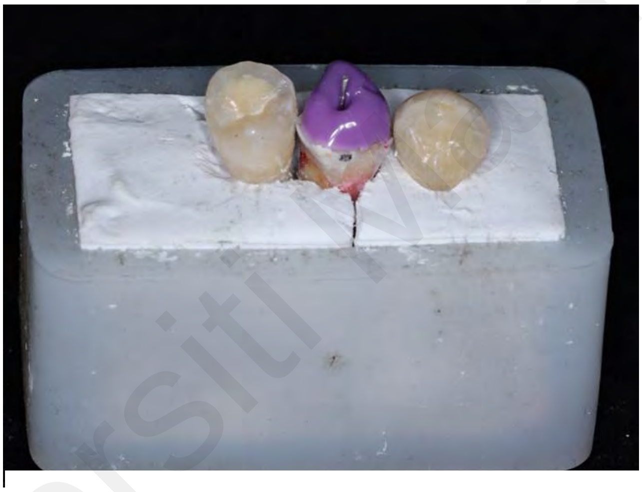


Figure 3.6 PVS impression

Figure 3. 7 PVS Impression obtained after removal from post space

3.2.6.3 Combination impression technique

Following the traditional impression technique, the polyvinyl siloxane (PVS) impressions were subjected to digital scanning using both the Trios 5 and the Primescan to obtain the combination impression technique files.

Figure 3. 8 Mounting of PVS impression onto plasticine

Each PVS impression was securely positioned upside down with the free end of the paper clip pin mounted on a plasticine block to ensure stability during the scanning process.

The impression was scanned with the same scanning sequence as Figure 3.4 and was scanned twice. Each scanning produced an STL file which was named and saved onto a pen drive.

Figure 3.9 is a summary of the scans and impressions taken and obtained for each tooth.

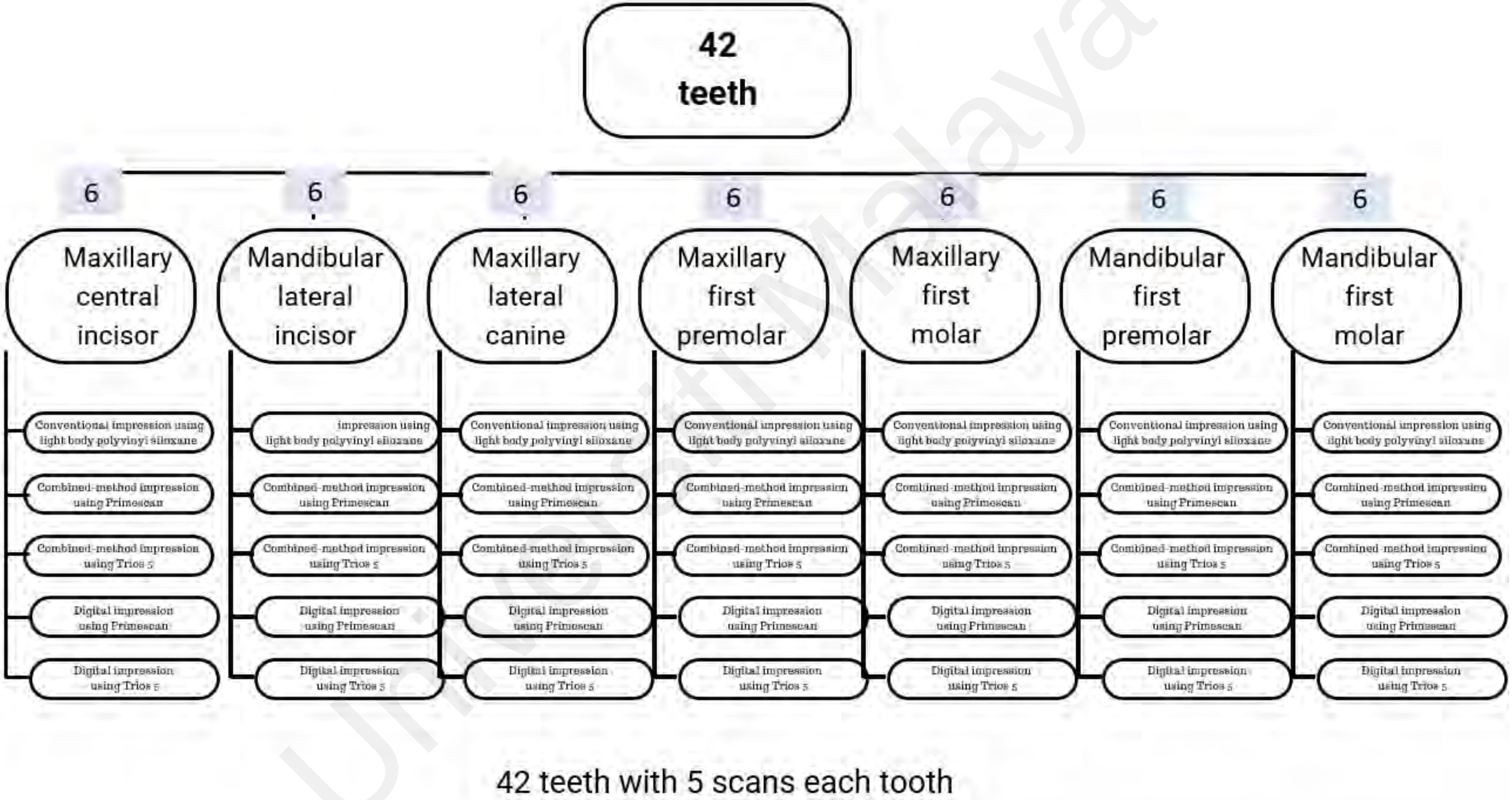


Figure 3. 9 Impressions obtained

3.2.7 Data Collection and Investigation

3.2.7.1 Accuracy of Depth Assessment

The depth of post-space preparation of each sample tooth was calculated by placing a K-file in the canal and marked using a silicone stop which was measured with a digital gauge. This value would then be used as the control group. The measurements obtained from the PVS impressions and the STL files will be compared to this control group value.

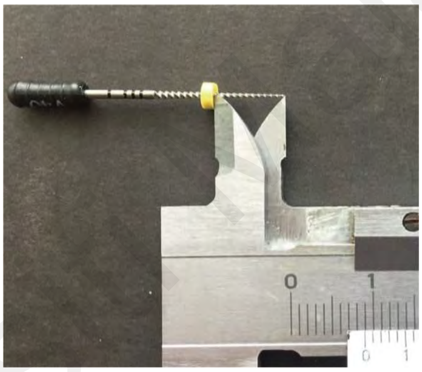


Figure 3. 10 K file measured with gauge

Each PVS impression was measured with digital callipers manually. The PVS impressions were measured 3 times each and the mean value was taken as the measurement.

The STL files generated from the scanned images were imported into Exoviewer3D 2.4 software for precise measurement and analysis. The depth of the post space was measured using this software following a standardized procedure. The measurement of the post space depth was conducted using two specific reference points within the Exoviewer3D 2.4 software:

- **First Point**: The first reference point was set in the middle of the coronal region of the sample tooth. This point served as the starting point for the depth measurement.
- **Second Point**: The second reference point was placed at the deepest middle end of the post space. This point marked the endpoint of the depth measurement.

Figure 3. 11 Points taken for Measurement of Depth of Post Space

The software calculated the linear distance between the two points, providing an accurate measurement of the post space depth. This method ensured a consistent and reliable approach to measuring the depth across all samples. The depth measurements obtained from Exoviewer3D 2.4 were recorded systematically for each sample. This data was then used for subsequent analysis, allowing for a comprehensive comparison of the post space depths obtained from the different scanning techniques.

3.2.7.2 Assessment of Reproducibility of Anatomic Space Reading

The assessment of reproducibility aimed to evaluate the ability of the Trios 5 and Primescan intraoral scanners to produce consistent and undistorted images of the same sample. Additionally, the analysis sought to identify any distortions and quantify their degree and location. This was achieved through a systematic process of superimposing and comparing the STL files generated by the two scanners.

The STL files obtained from the Trios 5 and Primescan scanners for the same sample were imported into a Medit link 3.3.1 3D imaging software capable of precise superimposition.

Additionally, STL files generated using the combination method—where both scanners were used sequentially or in tandem—were also superimposed for comparison.

The superimposition process involved aligning the STL files to ensure that they overlapped correctly, and this was done with the software's auto alignment.

The data image was then reversed to measure the impression area of the post space and the deviation display mode was turned on.

The superimposed images were compared in three distinct regions: the coronal third, the middle third, and the apical third of the post space.

The software calculated the differences between the superimposed images in each of the three regions. Measurements focused on identifying any deviations, distortions, or discrepancies between the scans produced by the two different scanners.

The degree of similarities was recorded and quantified by measuring the extent of the similarity and the overall degree of similarity in terms of percentage was also recorded.

The differences observed in the coronal third, middle third, and apical third were categorized based on the magnitude of the measured discrepancies. Figure 3.12 shows how the superimposition is done, and Figure 3.13 shows how the software calculates the similarities and deviations.

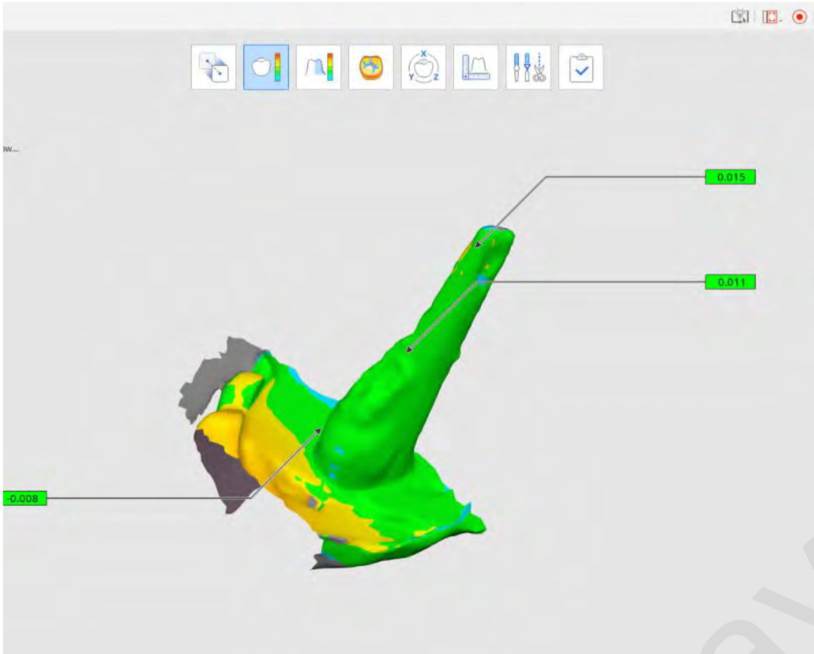


Figure 3. 12 Superimposition of two reversed STL files, and measurements in coronal third, middle third and apical third shown.

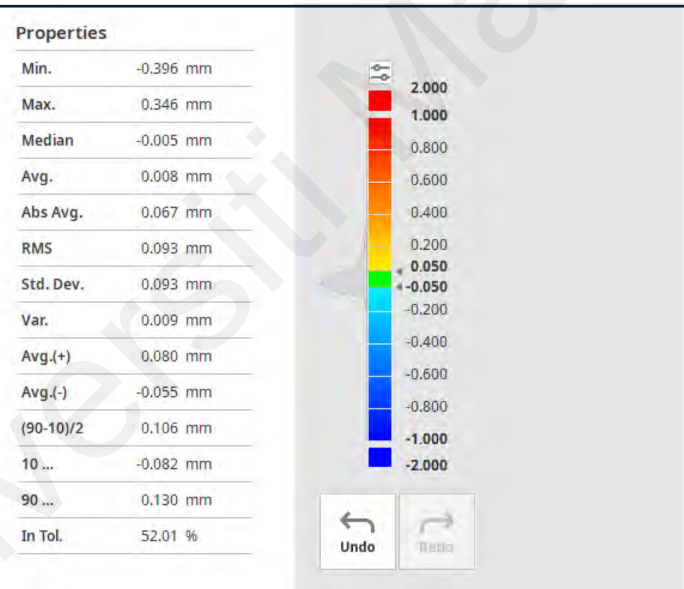


Figure 3. 13 Interpretation of values from the software when the superimposition is done

3.3 Intra Examiner Calibration

Intra-examiner calibration was done to ensure the consistency and reliability of measurements of the Trios 5 and Primescan scans. Since assessments are made by a single examiner intra-class correlation coefficient was applied.

This was done by scanning and rescanning 21 samples out of the 42 samples and measuring the depth of post space on the software Exoviewer3D 2.4 software. (Align Technology ®, Germany))

The results were then inserted into SPSS to analyse the intra-class correlation coefficient.

3.4 Statistical analysis

The data were analysed using Statistical Program for Social Sciences software (SPSS, Version 29 IBM, NY, USA).

Normality of the data distribution was assessed using the Kolmogorov–Smirnov test and skewness. Means and standard deviations of the study group for depth of post space and reproducibility were compared.

Data for depth of post space was found to be non-parametric. Hence, a pairwise comparison of impressions and the Kruskal- Wallis Test was applied.

As for reproducibility, a t-test was applied followed by the Tukey multiple comparison test

A p-value of less than 0.05 ($p<0.05$) was considered statistically significant among group comparisons. An assessment of possible correlations between the independent variables (type of tooth and type of impression) and dependent variables (depth of post space and reproducibility) was done.

CHAPTER 4: RESULTS

4.1 Intra-class correlation

The Intraclass Correlation Coefficient (ICC) results for Trios 5 (Table 4.1) and Primescan (Table 4.2) highlight their reliability in measuring post impressions. For Trios 5, the ICC values are 0.929 for single measures and 0.963 for average measures, with 95% confidence intervals indicating high reliability and consistency. The F-test values of 27.184 further support this reliability. In comparison, Primescan exhibits perfect reliability, with ICC values of 1.000 for both single and average measures and 95% confidence intervals of [1.000, 1.000]. The extremely high F-test value of 57145.129 underscores the absolute consistency of Primescan measurements. Overall, both systems demonstrate excellent reliability, with Primescan achieving perfect measurement consistency.

Table 4.1: Intraclass Correlation Coefficient results for Trios 5

		95% Confidence Interval		F Test with True Value 0		
	Intraclass Correlation[b]	Lower Bound	Upper Bound	Value	df1	df2
Single Measures	.929[a]	.836	.970	27.184	20	20
Average Measures	.963[c]	.911	.985	27.184	20	20

Table 4.2: Intraclass Correlation Coefficient results for Primescan

		95% Confidence Interval		F Test with True Value 0		
	Intraclass Correlation[b]	Lower Bound	Upper Bound	Value	df1	df2
Single Measures	1.000[a]	1.000	1.000	57145.129	20	20
Average Measures	1.000[c]	1.000	1.000	57145.129	20	20

4.2 Accuracy of Depth of Post Space

A Pairwise Comparison was done to compare the accuracy of the depth of post space reading with 3 methods of obtaining an impression. Method 1 which is obtaining a PVS impression manually and traditionally. Method 2 is scanning the post space with Trios 5 and method 3 is scanning the post space with the Primescan. The comparisons aim to determine whether the distributions of various impression methods are significantly different from each other. Table 4.3 below shows the Pairwise Comparison of Impressions.

Table 4.3: Pairwise Comparison of Impressions

Sample 1 - Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Significance	Adj. Significance
Trios 5 - Primescan	-57.536	10.605	-5.425	<.0.001	0.000
Trios 5 - PVS	78.750	10.605	7.425	<0.001	0.000
Trios 5 - Control	96.000	10.605	9.052	<0.001	0.000
Primescan - PVS	21.214	10.605	2.000	0.045	0.273
Primescan - Control	38.464	10.605	3.627	<0.001	0.002
PVS - Control	17.250	10.605	1.627	0.104	0.623

When comparing the recording of the depth of post space, the comparison between Trios 5 and Primescan, Trios 5 and PVS, Trios 5 and control and Primescan and control showed significant difference ($p < 0.05$) while when Primescan is compared to PVS and PVS compared to the control, it showed no significant difference ($p > 0.05$). These results have been summarised in Figure 4.1 below.

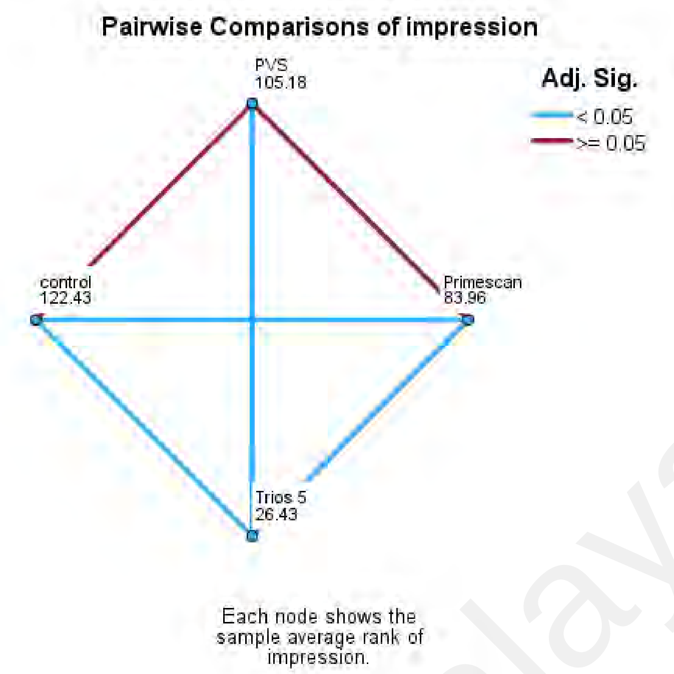


Figure 4. 1: Summary of Pairwise Comparison

The box plot in Figure 4.2 illustrates the results of an Independent-Samples Kruskal-Wallis Test, used to compare the depth measurements of different impression techniques.

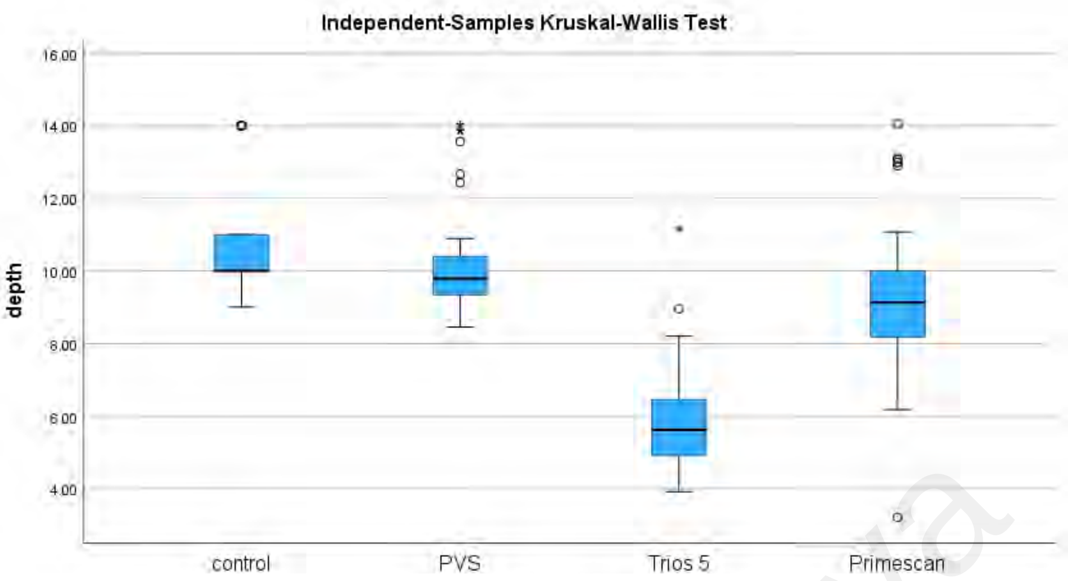


Figure 4.2 Box plot of Independent- Samples Kruskal Wallis Test Comparing Depth Recorded

The techniques evaluated include the control group, polyvinyl siloxane (PVS), Trios 5, and Primescan. The y-axis represents the depth measurements, while the x-axis denotes the different impression methods.

The presence of multiple outliers and the differences in IQRs suggest variability in the accuracy and precision of the depth measurements across the different impression techniques.

When comparing control vs. PVS, the control and PVS groups exhibit similar medians and variability, indicating that the PVS method produces depth measurements comparable to the control group.

When comparing Trios 5 vs. Control/PVS, the Trios 5 group shows significantly lower median depth measurements and higher variability, indicating potential underestimation of depths and less consistent results.

When comparing Primescan vs. Control/PVS, the Primescan group, while showing some improvement over Trios 5, still has a lower median and higher variability compared to the control and PVS groups.

The box plot and the results of the Kruskal-Wallis Test indicate significant differences in the depth measurement accuracy among the different impression techniques. The control and PVS methods demonstrate more consistent and accurate depth measurements, while the Trios 5 and Primescan methods show greater variability and potential inaccuracies.

4.3 Reproducibility of impression methods

The reproducibility of the impression methods was measured by superimposing the Trios 5 scan to the Primescan scan and checking for the percentage of similarity between the 2 scans.

The PVS impression scanned with Trios 5 was also superimposed on the PVS impression scanned by the Primescan and the percentage of similarity was recorded.

An independent-sample Mann-Whitney U Test was used to compare the percentage similarity when the image superimpositions: Trios 5 to Primescan and PVS-Trios 5 to PVS-Primescan. Figure 4.3 and Table 4.4 depicts the output results.

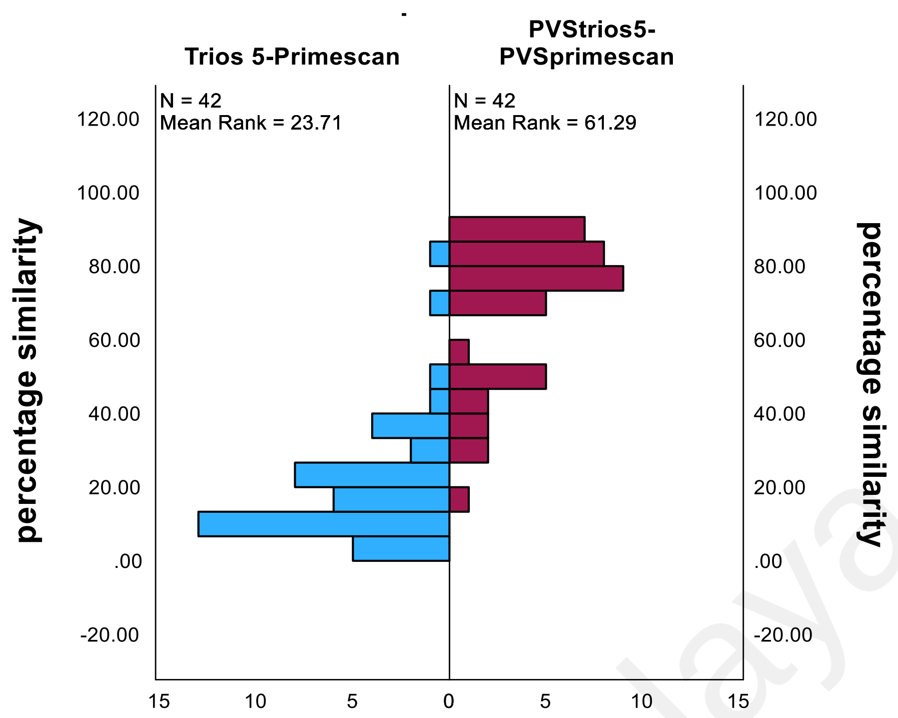


Figure 4.3 Independent- Samples Mann-Whitney U Test Comparing Overall Percentage Similarity

Table 4.4: Independent-Samples Mann-Whitney U Test Summary

Total N	84
Mann-Whitney U	1671.000
Wilcoxon W	2574.000
Test Statistic	1671.000
Standard Error	111.780
Standardized Test Statistic	7.058
Asymptotic Sig. (2-sided test)	<.001

In terms of the distribution of percentage similarity, the Trios 5-Primescan group has a lower mean rank (23.71), indicating lower percentage similarity values. The PVS-Trios5-PVS-Primescan group has a higher mean rank (61.29), indicating higher percentage similarity values.

The frequency distribution for the Trios 5-Primescan group shows that most of the percentage similarity values are concentrated in the lower range (0-40%), with very few instances above this range. The frequency distribution for the PVS-Trios5-PVS-Primescan group shows that the percentage similarity values are more evenly distributed across a wider range, with a significant number of instances in the higher range (60-100%).

The Mann-Whitney U Test results in the graph show a clear difference between the two groups, with the PVS-Trios5-PVS-Primescan method having significantly higher percentage similarity values compared to the Trios 5-Primescan method. This is further supported by the statistical significance (asymptotic significance < .001).

The results indicate that the PVS-Trios5-PVS-Primescan method provides higher reproducibility in terms of percentage similarity compared to the Trios 5-Primescan method. The higher mean rank and the broader distribution of higher similarity percentages for the PVS-Trios5-PVS-Primescan group suggest that this method yields more consistent and accurate impressions. This significant difference ($p < 0.05$) highlights the superior performance of the PVS-based method in capturing detailed and accurate anatomical spaces which are reproducible.

The mean percentage of similarity according to the type of tooth comparing both methods is shown in Table 4.5 below.

Table 4.5: Mean Percentage of Similarity and Standard Deviation for Different Types of Teeth with superimposing Trios 5 to Primescan and PVS Trios- PVS Primescan Methods

Type of Tooth	Superimposition	Mean %	N	Std. Deviation
Mandibular Incisor	Trios-Primescan	34.5017	6	8.39417
	Pvstrios-Pvsprimescan	69.1133	6	18.89566
	Total	51.8075	12	22.82631
Maxillary Canine	Trios-Primescan	17.6217	6	11.94279
	Pvstrios-Pvsprimescan	62.2017	6	23.85876
	Total	39.9117	12	29.42090
Maxillary 1st Premolar	Trios-Primescan	24.2050	6	23.71990
	Pvstrios-Pvsprimescan	72.5583	6	23.14437
	Total	48.3817	12	33.71756
Mandibular 2nd Premolar	Trios-Primescan	28.0033	6	28.99151
	Pvstrios-Pvsprimescan	49.3233	6	24.17326
	Total	38.6633	12	27.77817
Maxillary 1st Molar	Trios-Primescan	12.4617	6	5.79490
	Pvstrios-Pvsprimescan	81.6433	6	5.32165
	Total	47.0525	12	36.51626
Mandibular 1st Molar	Trios-Primescan	8.8000	6	6.33468
	Pvstrios-Pvsprimescan	69.2367	6	18.23903
	Total	39.0183	12	34.14105
Maxillary Central incisor	Trios-Primescan	22.0783	6	10.47916
	Pvstrios-Pvsprimescan	75.5767	6	6.20195
	Total	48.8275	12	29.11982

The results demonstrate variability in the percentage of similarity between the superimposition methods of Trios to Primescan and PVS-Trios to PVS-Primescan across different types of teeth. Generally, the PVS-Trios to PVS-Primescan method exhibited higher mean percentages of similarity compared to the Trios to Primescan method alone, indicating that the PVS impression method may offer better reproducibility.

Notably, the maxillary 1st molar showed the highest reproducibility accuracy, with a mean similarity percentage of 81.6433% using the PVS-Trios to PVS-Primescan superimposition method. Conversely, the mandibular first molar recorded the lowest reproducibility accuracy, with a mean similarity percentage of 8.8000% using the Trios to Primescan superimposition method.

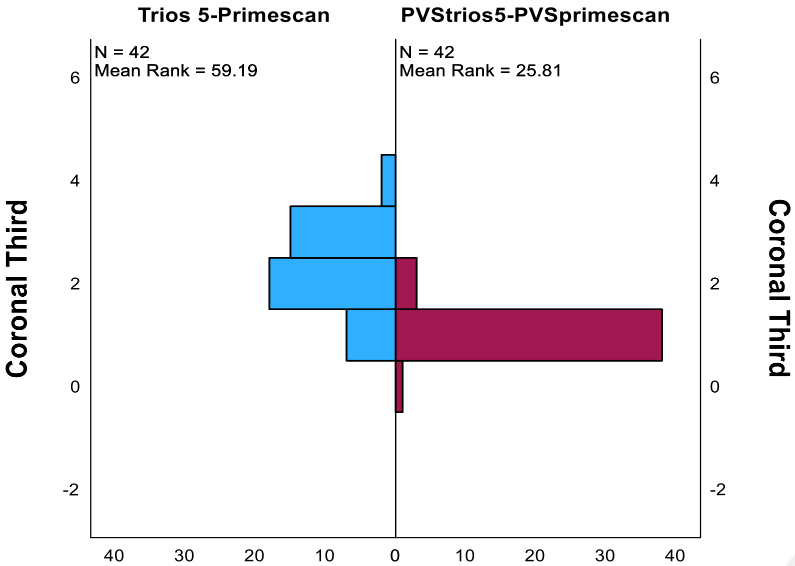
These findings suggest that while the PVS impression method tends to provide higher reproducibility across most tooth types, there is significant variability, with some tooth types showing much higher or lower reproducibility depending on the method used.

4.3.1 Deviation of reproducibility by regions

Independent- Samples Mann- Whitney U test was also applied to compare the deviation in recording at 3 different regions of the teeth: Coronal third, Middle third and Apical third.

4.3.1.1 Coronal Third

Figure 4.4 and Table 4.6 show the summary of the applied independent- samples Mann-Whitney U Test for the Coronal Third region.



Legend	Deviation (mm)
0	No difference
1	0.01-0.05
2	0.06-0.4
3	0.4-0.8
4	0.8-2.0
5	Not recorded

Figure 4.4 Independent- Samples Mann-Whitney U Test Comparing Measurement Difference in the Coronal Third

Table 4.6: Independent- Samples Mann-Whitney U Test Summary Comparing Measurement Difference in Coronal Third

Total N	84
Mann-Whitney U	181.000
Wilcoxon W	1084.000
Test Statistic	181.000
Standard Error	101.533
Standardized Test Statistic	-6.904
Asymptotic Sig.(2-sided test)	<.001

The frequency distribution, categorized by the deviation legend in Figure 4.4, reveals that the majority of values for the PVS Trios 5- PVS Primescan group fall within categories 1 and 2, corresponding to deviations of 0.01-0.4 mm. This indicates high similarity, with few instances categorized as 3 or higher, meaning deviations larger than 0.4 mm are rare in this group.

In contrast, the Trios5-Primescan group shows a different distribution, with more values falling into categories 3 and 4, corresponding to deviations of 0.4-2.0 mm. This indicates less similarity, with larger deviations being more common. Fewer values fall within the categories of 1 and 2 for this group, highlighting that larger deviations are more prevalent with the Trios 5-Primescan method.

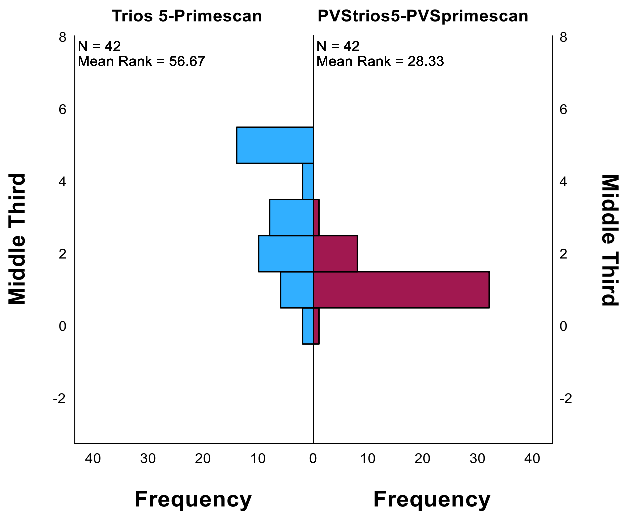
Overall, the results suggest that the PVS Trios 5-PVS Primescan method provides superior reproducibility for the coronal third of the impression, demonstrating less deviation and higher similarity compared to the Trios 5-Primescan method.

These results indicate that the PVS Trios 5-PVS Primescan method provides superior reproducibility for the coronal third of the impression, demonstrating less deviation and higher similarity.

In Table 4.4, the results of the Mann-Whitney U Test indicate a significant difference in the similarity of the coronal third between the Trios 5-Primescan and PVS-Trios5-PVS-Primescan methods.

4.3.1.2 Middle Third

Figure 4.5 and Table 4.7 show the summary of the applied independent- samples Mann-Whitney U Test for the Middle Third region.



Legend	Deviation (mm)
0	No difference
1	0.01-0.05
2	0.06-0.4
3	0.4-0.8
4	0.8-2.0
5	Not recorded

Figure 4. 5 Independent- Samples Mann-Whitney U Test Comparing Measurement Difference in the Middle Third

Table 4.7: Independent- Samples Mann-Whitney U Test Summary Comparing Measurement Difference in Middle Third

Total N	84
Mann-Whitney U	287.000
Wilcoxon W	1190.000
Test Statistic	287.000
Standard Error	105.560
Standardized Test Statistic	-5.637
Asymptotic Sig. (2-sided test)	<.001

The graph in Figure 4.5 presents the results of an Independent-Samples Mann-Whitney U Test comparing the similarity of the middle third when superimposing images: Trios 5 to Primescan and PVS-Trios 5 to PVS-Primescan.

The frequency distribution, categorized by the deviation legend in Figure 4.5, reveals that the majority of values for the superimposition of PVS Trios 5-PVS Primescan group fall within categories 1 and 2, corresponding to deviations of 0.01-0.4 mm. This indicates high similarity, with few instances categorized as 3 or higher, meaning deviations larger than 0.4 mm are rare in this group.

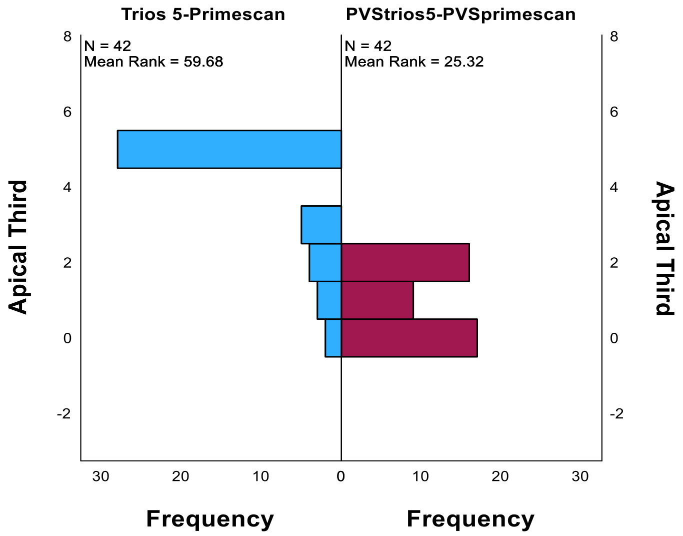
In contrast, the Trios 5-Primescan group shows a different distribution, with more values falling into categories 3 and 4, corresponding to deviations of 0.4-2.0 mm. This indicates less similarity, with larger deviations being more common. Fewer values fall within the categories of 1 and 2 for this group, highlighting that larger deviations are more prevalent with the Trios 5-Primescan method. A large number of samples showed that the middle third was not recorded in this group indicating that the Trios 5 could not record the middle third of the post space in some instances.

Overall, the results suggest that the PVS Trios 5-PVS Primescan method provides superior reproducibility for the middle third of the impression, demonstrating less deviation and higher similarity compared to the Trios 5-Primescan method. Hence the combination technique of a PVS impression and then scanning the impression with an intraoral scanner showed greater reproducibility as compared to just scanning the post space with an intraoral scanner.

In Table 4.7, the results of the Mann-Whitney U Test indicate a significant difference ($p < 0.05$) in the similarity of the middle third between the Trios 5-Primescan and PVS-Trios5-PVS-Primescan methods.

4.3.1.3 Apical Third

Figure 4.6 and Table 4.8 show the summary of the applied independent- samples Mann-Whitney U Test for the Apical Third region.



Legend	Deviation (mm)
0	No difference
1	0.01-0.05
2	0.06-0.4
3	0.4-0.8
4	0.8-2.0
5	Not recorded

Figure 4.6 Independent- Samples Mann-Whitney U Test Comparing Measurement Difference in the Apical Third

Table 4.8: Independent- Samples Mann-Whitney U Test Summary Comparing Measurement Difference in the Apical Third

Total N	84
Mann-Whitney U	160.500
Wilcoxon W	1063.500
Test Statistic	160.500
Standard Error	108.081
Standardized Test Statistic	-6.676
Asymptotic Sig. (2-sided test)	<.001

The graph in Figure 4.6 presents the results of an Independent-Samples Mann-Whitney U Test comparing the similarity of the apical third when superimposing images: Trios 5 to Primescan and PVS-Trios5 to PVS-Primescan.

The frequency distribution, categorized by the deviation legend, reveals that the majority of values for the PVS Trios 5-PVS Primescan group fall within categories 1 and 2, corresponding to deviations of 0.01-0.4 mm. This indicates high similarity, with few instances categorized as 3 or higher, meaning deviations larger than 0.4 mm are rare in this group.

In contrast, the Trios5-Primescan group shows a different distribution, with most of the values falling into categories 5, corresponding to the apical region not being recorded at all by the Trios 5. This indicates less similarity, with larger deviations being more common. Fewer values fall within the categories of 1 and 2 for this group, highlighting that larger deviations are more prevalent with the Trios5-Primescan method. This shows that at deeper levels, the Trios 5 is unable to capture the depth of the post space as compared to the Primescan since the Trios 5 images were superimposed onto the Primescan images on the software.

Overall, the results suggest that the PVS Trios 5-PVS Primescan method provides superior reproducibility for the apical third of the impression, demonstrating less deviation and higher similarity compared to the Trios 5-Primescan method. Hence the combination technique of a PVS impression and then scanning the impression with an intraoral scanner showed greater reproducibility as compared to just scanning the post space with an intraoral scanner for the apical region as well.

In Table 4.9, the results of the Mann-Whitney U Test indicate a significant difference ($p < 0.05$) in the similarity of the apical third between the Trios 5-Primescan and PVS-Trios 5-PVS-Primescan methods.

CHAPTER 5: DISCUSSION

5.1 Methodology

5.1.2 Sample Preparation

In the present study, different morphologies of teeth were included to provide a more comprehensive evaluation of the reproducibility and accuracy of the intraoral scanners (Trios 5 and Primescan). This approach contrasts with previous studies that may have focused on a single type of tooth (Pinto, 2017) (Elter et al., 2022) or two types of tooth (Emam et al., 2023), thereby limiting the generalizability and applicability of their findings. Different types of teeth (e.g., incisors, canines, premolars, molars) exhibit varying levels of anatomical complexity. Molars, for example, have more intricate occlusal surfaces compared to incisors. Previous studies focusing on a single tooth type might not capture the full range of challenges posed by these anatomical differences. By including a variety of tooth morphologies, the study can evaluate how well the scanners perform across different levels of complexity. This comprehensive approach helps identify any limitations or strengths of the scanners that might only become apparent when dealing with more intricate tooth structures.

Radiographs were taken before the preparation of the tooth and after root canal treatment. This imaging was essential for evaluating preparation processes. By utilizing both photographic and radiographic documentation at multiple stages, the study ensured a thorough and precise evaluation of the teeth, enabling an accurate analysis and comparison of conditions before and after the treatment.

The working length of each tooth was checked with a size 10 K-file. The file was gently inserted into the root canals until its tip became just visible at the apical foramen This is a standard practice aimed at avoiding over-instrumentation and ensuring the preservation of apical constriction. This critical step in the preparation process ensured that subsequent procedures, such as cleaning, shaping, and obturation, were performed within the correct anatomical confines, thereby enhancing the overall success and predictability of the endodontic treatment

The decision to add two adjacent teeth to the block was to enhance the clinical relevance of the study. Including adjacent teeth in the scan ensures that the anatomical structures surrounding the target tooth are realistically represented. This is vital for accurate modelling and fabrication of restorations.

One study demonstrated that the inclusion of adjacent teeth significantly improves the accuracy of digital impressions by providing a more complete and realistic representation of the dental arch (Guth et al., 2013).

Adding adjacent teeth to the block for scanning is also crucial for several reasons that enhance the accuracy and reliability of the scanning process. This approach is designed to mimic the clinical situation, providing a more realistic representation of the actual conditions under which intraoral scanning occurs. In a real clinical setting, adjacent teeth provide important contextual landmarks that help in orientating the scanner and ensuring that the target tooth is captured accurately. Without these landmarks, the scanner might struggle to maintain consistent positioning, leading to potential inaccuracies. Studies such as (Mangano et al., 2017) have shown that including adjacent teeth improves the precision of digital impressions by providing more reference points, which helps in aligning the scans accurately.

The standard post depth or length is generally 2/3 to ¾ of the root length. The post space preparation should extend deep enough to ensure that the post is at least as long as the clinical crown, but it should not extend beyond the middle third of the root (Reich et al., 2024). Typically, the standard post depths range between 8 to 12 mm, depending on the clinical requirements and the specific tooth being restored. This range is considered optimal for providing sufficient mechanical retention while minimizing the risk of perforation or compromising the structural integrity of the tooth.

In this study, the post depths were systematically controlled based on the type of tooth to align with these standard depths, ensuring that the evaluation of impression methods accurately reflects clinical practice. The depth was standardised across the same type of tooth to reflect more accurate and reliable results. The box plot and pairwise comparisons revealed significant variability in depth readability across different impression methods, highlighting the differences in their ability to capture the full depth of the posts accurately.

As for impression taking with traditional PVS material, light body PVS was used. The viscosity of the light body PVS was particularly suitable for this application, as it allows for more precise flow and adaptation to the intricate details of the post-space

5.1.3 Scanners

The dental field is increasingly adopting CAD/CAM technology for a wide range of restorations, revolutionizing practices with enhanced precision and efficiency. However, there remains a significant gap in the widespread use of this technology for custom-made posts.

Trios 5 and Primescan were chosen for this study due to their recognized superior accuracy and advanced technological features compared to other brands of intraoral scanners available in the market (Roth et al., 2022).

However, based on current literature, intraoral scanners face significant challenges in accurately capturing deep narrow spaces due to several optical principles and physical constraints (Emam et al., 2023). When light from the scanner hits a dental surface, it reflects back to the sensor. However, in deep narrow spaces, the angle and intensity of reflected light are reduced, complicating data capture. Additionally, light entering these spaces often refracts or bends, distorting the image and leading to inaccuracies in the digital impression.

Shadowing and occlusion further hinder the scanner's ability to capture complete data. Parts of the narrow space can be shadowed by surrounding structures, resulting in incomplete images. Narrow canals can also occlude light paths, making it difficult for the scanner to visualize the full depth and contours of the space.

Moreover, light scatter and absorption add to the problem. Irregular surfaces within the canal cause light to scatter in multiple directions, reducing the precision of the reflected light. Certain materials within the canal can absorb light, diminishing the reflected light's intensity and clarity.

Physical constraints also play a role. The scanner's tip may be too large to access the deepest parts of narrow canals, limiting its ability to position the light source and sensor optimally. The scanner's depth of field might be insufficient to capture the entire depth of narrow canals, leading to blurred or incomplete data. Variability in surface reflection properties and complex geometries with multiple curves further complicate accurate scanning (Park et al., 2020).

These challenges highlight the limitations of intraoral scanners in capturing detailed impressions of deep narrow spaces, impacting the accuracy of digital dental impressions.

5.1.4 Scanning

In the present study, a constant scanning distance of 4mm was used for all samples with both the Trios 5 and Primescan intraoral scanners. This choice of distance was made to standardize the scanning process and ensure consistency across all measurements. The selection of 4mm is based on other research indicating that the optimal scanning distance for achieving the highest accuracy lies between 2.5mm and 5mm (Kim et al., 2019).

5.2 Results

The obtained results necessitated the rejection of both the null hypothesis. The pairwise comparisons demonstrate significant differences in depth readability between several impression methods, necessitating the rejection of the null hypothesis. The control and PVS methods provide better depth readability than the Trios 5 method, while the Primescan method performs comparably to the PVS method but better than Trios 5. These findings highlight the superior performance of traditional PVS impressions and the Primescan digital method in capturing depth accurately compared to the Trios 5 scanner.

The box plot from the Kruskal-Wallis test provides clear evidence of significant differences in depth readability among the control, PVS, Trios 5, and Primescan groups. The control and PVS groups show consistent and reliable depth readability, while the Trios 5 group demonstrates greater variability and less accurate readings. The Primescan group, though slightly more variable than the PVS group, shows better depth readability than the Trios 5 group.

The rejection of the second null hypothesis is justified by the statistically significant results obtained from the analyses. The study demonstrated that the combination of PVS and digital methods provides significantly higher reproducibility and accuracy compared to the digital methods alone. These findings indicate that the observed differences are genuine and not attributable to random chance, leading to the conclusion that the combined PVS and digital scanning method is more effective for capturing accurate post-space dental impressions.

While the use of real extracted teeth in dental research provides valuable clinical relevance, it also introduces variability due to anatomical differences within the same group type of teeth. Teeth of the same morphological type (e.g., molars, incisors) can vary greatly in size, shape, and structural complexity. These differences can affect how well the scanners capture details, potentially leading to variability in the reproducibility and accuracy of the impressions.

5.2.1 Comparison to Previous Studies

Previous studies have similarly highlighted the advantages and limitations of digital impressions. For instance, Alkadi (2023) emphasized the high accuracy of IOS in capturing surface details but noted challenges in deeper regions of the tooth post space. Dupagne et al. (2023) found that while IOS could provide high reproducibility, traditional PVS impressions often yielded better results in capturing the complete post space. The results from our study and the study by Pinto et al. (2017) collectively highlight the advancements in intraoral scanner technology and the remaining challenges in capturing accurate impressions in deep narrow spaces. While newer scanners like Primescan have shown significant improvements, issues with optical limitations persist, emphasizing the need for ongoing technological developments to address these challenges fully. These findings are consistent with our study, which found superior reproducibility with the combination of PVS impressions and digital scanning.

5.3 Limitations of study

This present study has several limitations. Firstly, the sample size of 42 in this study, while sufficient for initial comparisons, could be considered small. Larger sample sizes could provide more robust results and reduce the impact of outliers. Utilized larger sample sizes, offer more comprehensive data and potentially more reliable statistical power.

Another limitation is the focus on specific models of scanners, namely Trios 5 and Primescan. The rapid advancement in scanning technology means that newer models might offer improved performance. Comparison can be made with more brands of scanners to compare accuracy.

The use of artificial intelligence (AI) in intraoral scanners, such as Trios 5 and Primescan possess a challenge in the reliability of the results. The ability to manually disable AI in Trios 5 but not in Primescan adds an additional layer of complexity, potentially affecting the study's comparability and the reliability of its conclusions. It is crucial to consider these limitations when interpreting the results. In this study, the AI was manually disabled for Trios 5.

Additionally, if this study was conducted under in-vitro conditions, the results may not fully translate to clinical settings where factors such as patient movement, saliva, and other intraoral conditions play a role. Studies conducted under in-vivo conditions may provide results that are more applicable to everyday clinical practice.

The impression technique used in this study was the indirect method. Comparison of accuracy could have also been made to compare the direct method of impression taking of post space.

This study involved a single operator for impression taking. While this creates standardisation in impression taking across all samples, it does have some disadvantages. Involving multiple operators in the process of taking dental impressions offers significant advantages over using a single operator. It enhances the generalizability, reliability, and validity of the findings, reduces operator bias, provides a comprehensive assessment of the technique across different skill levels, identifies training needs, and increases the robustness and external validity of the study. These benefits contribute to a more accurate and realistic understanding of the performance and applicability of dental impression techniques in clinical practice.

The methods used for superimposing and analysing STL files, while precise, may differ with different software. Variability in software and analysis techniques can influence the results affecting the comparability of outcomes to other studies.

Furthermore, this study focused on the coronal, middle, and apical thirds of the post space, which is specific. It may not fully capture the overall accuracy of impressions across different regions. To have a better insight into the accuracy of impressions, producing a post for the impression and comparing it would be a better comparison for accuracy in various anatomical areas.

Finally, the use of the Mann-Whitney U Test is appropriate, but other statistical methods or additional analyses (e.g., regression analysis) could provide more insights.

While this study offers valuable insights into the reproducibility and accuracy of intraoral scanning methods compared to traditional PVS impressions, it is important to acknowledge these limitations. Future research should aim to address these issues by including larger and more diverse samples, incorporating newer technologies, and utilizing a broader range of analytical techniques. By considering these factors, subsequent studies can build on the findings of this research and contribute to the development of more accurate and reliable dental impression methods.

CHAPTER 6: CONCLUSION

6.1 Conclusion

Within the limitation of this study, based on the findings, the following conclusions were drawn:

- The traditional PVS impression method is superior in comparison to digital impression methods in recording post-space depth.
- Primescan is superior to Trios 5 in recording post-space depth.
- The combination method of PVS-Trios 5 and PVS-Primescan had a higher percentage similarity and better reproducibility compared to digital methods with Trios 5 and Primescan.
- Significant differences were observed in all three regions (coronal, middle, apical third) with the PVS-Trios 5-PVS-Primescan method consistently outperforming the digital scanning methods with Trios 5 and Primescan.
- The combination technique of traditional PVS impressions followed by digital scanning is more reliable for accurate and reproducible post-space impressions.

The results indicate that the PVS-Trios 5-PVS-Primescan method generally provides better reproducibility and higher similarity across all regions (coronal, middle, and apical third) compared to digital scanning methods with Trios 5 and Primescan method alone. The traditional PVS impression combined with digital scanning methods showed superior performance in capturing detailed and accurate impressions of post spaces.

These findings highlight the importance of using combined traditional and digital methods for more accurate dental impressions, which can significantly impact clinical outcomes in restorative dentistry.

6.2 Recommendations

Recommendations for future research include investigating other intraoral scanner brands and trying different methods to incorporate and increase the accuracy of the usage of intraoral scanners for post-impression.

It is also recommended to explore strategies to mitigate the impact of AI, such as standardizing AI settings or conducting future research for AI-related variability.

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