In-vivo comparison of digital and conventional inter-occlusal records

by

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Abstract

Purpose: The objectives of this study were to evaluate the clinical accuracy and reproducibility of virtual inter-occlusal records of the CEREC intraoral scanning system. The presence or absence of inter-occlusal contacts on multiple virtual occlusal records will be compared with conventional polyvinyl siloxane (PVS) inter-occlusal records.

Materials and Methods: Three conventional inter-occlusal records followed by three virtual inter-occlusal records per side per participants were taken. Then three sites of close proximity (SCP) and three sites of clearance (SC) per side per participant were identified on the trans-illuminated conventional PVS inter-occlusal records. A total of sixty SCP and SC were identified for ten participants using the conventional PVS inter-occlusal records. The presence or absence of these sites were analyzed using CloudCompare Software.

Result: Sensitivity for the three-different virtual inter-occlusal records was between 82% and 87%. Specificity was higher with values between 93% and 97%. Positive predictive values for the three scans were 95%, 96%, and 93%, and the negative predictive values 84%, 86% and 88%. Only 74% of the SCP were detected consistently with all three repeated scans and 92% of the SC were identified accurately with all the three scans.

Conclusion: Accuracy of CEREC Omnicam intra-oral scanner is clinically acceptable, while reproducibility is fair.

Lay Summary

Digital technology is increasingly used in all aspects dentistry. The use of intra-oral scanners to capture tooth preparations for crown fabrication is becoming increasingly commonplace. The objective of this study is to evaluate the accuracy of a commonly used intraoral scanner to duplicate the anatomical bite.

Preface

This study was conducted under the direct supervision of Dr. Chris Wyatt. The research committee members included Drs. Chris Wyatt, Alan Hannam, and David Tobias.

Patterson Dental (6651 Fraserwood Pl, Richmond, British Columbia) donated the CEREC Omnicam intraoral scanner to the Faculty of Dentistry UBC, which was used for the study. Mr. Rick Miller, a CEREC specialist at Patterson Dental helped in converting the digital file obtained by CEREC Omnicam intraoral scanner into Standard Tessellation Language (STL). Dr. Faraj Edher contributed to the literature review and methodology of the current research as a result of his involvement in a previous in-vitro study testing virtual inter-occlusal records. Dr. Saraa Abdulateef collected all of the data and performed the analyses.

Ethics certificate of expedite approval (UBC CREB NUMBER: H17-00192) was obtained from the clinical research ethics board at the office of research office, UBC on April 12, 2017.

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List of Symbols

μm	Micrometer

List of Abbreviations

CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
CEREC®	Chair-side Economical Restoration of Esthetic Ceramics
MIP	Maximum Intercuspal Position
PVS	Polyvinyl Siloxane
SC	Sites of Clearance
SCP	Sites of Close Proximity
STL	Standard Tessellation Language

Glossary

Buccal bite scan: Virtual inter-occlusal record taken by CEREC.

Inter-occlusal Record: A registration of the positional relationship of the opposing teeth or arches.

Virtual inter-occlusal Record: A registration of the positional relationship of the opposing teeth or arches done by the intraoral scanning system.

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Dedication

I'd like to dedicate my thesis to my beloved parents, my father Dr. Dhafir Abdulateef Mahmood and my mother Dr. Reem Saeed. You have been a source of encouragement and inspiration to me throughout my life. I am truly grateful for your endless love, guidance, support and sacrifices. You have always encouraged me to believe in myself and pursue my dreams, instilling in me the confidence that I am able to achieve anything I set my mind to. Thank you for being such great role models.

Chapter 1: Introduction

1.1 Dental Occlusion

Natural dentition of the maxillary and mandibular arches come into contact in a static or a dynamic way. Static occlusal relationship usually occurs in maximal intercuspation (MIP), whereas dynamic occlusal relationship occurs during excursive mandibular movements such as protrusion and lateral eccentric positions. There are various ways in which opposing teeth occlude, static and dynamic teeth contacts might occur normally or with variations, which could be physiologically adaptive or pathological. Inter-occlusal records may be taken at MIP or various lateral and protrusive positions. Accurate inter-occlusal records are essential in order to restore function and occlusal stability with the fabricated prostheses.

1.2 Occlusal Contacts

Occlusal contacts are defined as the touching of opposing teeth on elevation of the mandible.[1] They increase in number as the two arches of teeth are brought together into occlusion until MIP is achieved. Location of occlusal contacts in this position is one of the key factors that maintain an accurate alignment of the arches. [2] Understanding the nature and distribution of occlusal contacts is essential for understanding how occlusal loads are dispersed and the effect of occlusion on biological structures, which facilitates precise diagnosis and planning of any restorative procedures.[3] Any modifications in the occluding surfaces because of dental treatment or functional wear of the teeth may result in loss of equilibrium and potentially pathologic occlusion.[4] The maximum intercuspal position contact areas have been measured in a number of ways.

1.3 Occlusal Indicators

Occlusal indicators are utilized to identify occlusal contacts between two opposing arches. In addition, they are used to detect occlusal interferences, which may require modification prior to prosthodontic treatment. [1, 5] Occlusal indicators can be categorized into two types: qualitative and quantitative indicators. Examples of qualitative methods are articulating papers, shimstock foil, silk, wax, plastic strips, and elastomeric impression material; all of which can be utilized to mark the number and location of occlusal contacts. On the other hand, quantitative methods can measure the force and timing of tooth contacts. The most common quantitative methods are Photocclusion, Dental Prescale, and T-Scan (Tekscan, South Boston, MA, USA).[6-8] More recently, dental casts alignment has been virtually analyzed by digitizing the casts or using an intraoral scan of the natural dentition.[7, 9, 10]

Qualitative occlusal indicators identify tooth to tooth contacts, yet are influenced by material thickness, type of dyes, moisture control in the oral cavity, the number of applications, anatomical features of the teeth, and the material itself.[11, 12] As a result, these types of occlusal indicators usually lack clinically acceptable specificity and sensitivity, which may explain the remarkable differences seen in the size, number and location of occlusal marks, and the frequency of false positive marks.[12, 13] Therefore, occlusal indicators need thorough interpretation by the clinician in addition to patient's feedback. [14]

Quantitative occlusal indicator methods provide additional information of occlusal load and timing of contacts.[13] The main limitation of these types of indicators is the thickness of the sensors, which could interfere with the normal occlusion.[7] The accuracy of inter-occlusal records using quantitative occlusal indicator methods has been questioned.[14]

In general, an ideal occlusal indicator should be accurate, reliable, have appropriate sensitivity and specificity and a thickness, which would not interfere with normal occlusion.[5, 8]

1.3.1 Articulating Papers and Ribbons

Articulating paper identifies occlusal contacts qualitatively by their location, size and shape. There is considerable variability in occlusal contacts identified by different types of articulating papers.[5] Materials used for different paper indicators vary in their thickness, strength, type of stain, and their backing, which are all potentially capable of creating variability in identifying occlusal contacts clinically.[5, 15]

It's generally assumed that dark marks with greater surface area suggest heavy occlusal contacts, while light marks with smaller area suggest lighter occlusal contacts. It is also assumed that obtaining several adjacent contact points with similar sizes indicate evenly distributed occlusal load.[16] However, no published studies were found to support these assumptions. In fact, previous research concluded that the size of occlusal mark does not represent occlusal loads. Thus, an operator cannot identify the sites of excessive load for occlusal adjustment based solely on occlusal markings. In addition, 50% of the occlusal contacts determined by occlusal mark areas were not reproducible using articulating paper. [17, 18]

Operator variability is significant using articulating papers; dental students with less clinical experience produced more variable occlusal markings in comparison to those taken by experienced dentists. Using the same piece of articulating paper repeatedly resulted in fewer marks, for this reason, it has been suggested that each ribbon should only be utilized once or twice. Another factor is the patient's head position resulting in different occlusal contacts. [13, 14, 19, 20] The thickness of articulating papers may or may not influence identifying occlusal contacts. When Accufilm (25 µm) was compared with articulating paper (60 µm), Saad et al[13] found that both systems have limited ability to identify contact areas and their outline. Other studies have found that thinner articulating papers had the most reliable outcome.[15, 21]

Other limitations of articulating papers include the oral environment factors such as moisture control, mobility of teeth and occlusal surface anatomy. Usually fewer occlusal contacts are observed in the presence of moisture, whereas greater occlusal contacts are identified with mobile teeth. As the occlusal surfaces get smoother, fewer occlusal markings are observed, which makes occlusal adjustments progressively harder. Furthermore, different cusp configurations such as round, flat or sharp cusps affect the occlusal marking as a result of closing forces and shape of opposing teeth. Another disadvantage is the inability to quantify or store occlusal markings for the future. Articulating paper has the advantages of immediate visualization, their availability at most dental offices in a variable range of thicknesses, ease of use, recording static and dynamic contacts, and is not influenced by closing forces. [5, 20]

1.3.2 Shimstock Foil

Humans are capable of detecting occlusal changes as low as 8-10 µm [22, 23], which is considerably less than the thickness of articulating papers. Thus, the use of shimstock, with a thickness of 8-13 µm [15, 24], may provide a more accurate assessment of the occlusal contacts. The recommended method of application is having the patient simultaneously bite on the shimstock while the clinician pulls at 90deg to the occlusal plane. The subjective comparison of the degree of resistance between the occlusal surfaces around the arch is made. However, this technique does not provide any information regarding the number, location, size, or force of the occlusal contacts.[24]

Shimstock foil and articulating paper techniques are used in combination to clinically identify occlusal contacts.[3, 24] Usually the articulating papers identifies the occlusal contacts, yet it tends to be prone to false-positive contacts [15], where the shimstock is able to confirm the true contacts.[25]

1.3.3 Silicone Inter-Occlusal Record Material and Trans-illumination

The physical properties of addition silicone make it an ideal material for identifying occlusal contacts. [7, 11] Due to their characteristics, several similar studies considered silicone inter-occlusal material as the gold standard with which other methods could be compared. These characteristics include low viscosity, which permits sufficient flow of the material with uniform distribution over the occlusal surfaces yet minimal interference during jaw closure, dimensional stability and accuracy.[5, 7] Thus, it has been found to be a reliable way for studying inter-occlusal relationships compared to other inter-occlusal record methods.[26-29]

Trans-illumination is a technique, which is utilized to quantify the occlusal contacts of silicone inter-occlusal records by measuring the transparency and comparing it to a known thickness.[7] Owens et al[30] considered areas of contact where the material have a thickness of 50 µm or less while areas of near contacts would be where the material have a thickness of more than 50 µm but less than 350 µm. Nevertheless, the results should be interpreted with caution, as they vary with different angles between the records and the imaging devices, which affect the amount of light passing through the material.[7] Different techniques have been used to trans-illuminate the silicone inter-occlusal records such as using Polariscope, flatbed scanners and placing the records in front of light source and visually detecting the contact points. [2, 3, 26, 31]

1.3.4 Other Occlusal Indicators

The T-Scan (Tekscan, South Boston, MA, USA) consists of a wafer thin U-shaped sensor with plastic coating and high resolution Sensels to detect occlusal contacts.[13] It's capable of digitally recording both the force and timing of occlusal contacts. The accuracy of T-Scan in occlusal analysis has shown promise by some, [25, 32] but other have found it to be associated with low accuracy and sensitivity due to the thickness of the sensor, which might interfere with registering the habitual occlusion.[8, 14]

Photo-occlusion is an occlusal indicator, which involves having the patient bite on a photo-elastic sheet and analyzing it under polarizing light. The areas demonstrating contacts are outlined so that quantitative and qualitative data can be obtained by transferring the results to a graphic occlusal scheme. However, mandibular movement is influenced by the thickness of the

firm plastic sheet resulting in increased posterior contacts and diminished anterior contacts.[6, 20]

Another method known as Occlusal Sketch involves drawing a diagram on acetate sheet to represent the occlusal surfaces of posterior teeth, palatal surfaces of maxillary anterior teeth and buccal surfaces of mandibular anterior teeth. [33] The location of the contact points is identified clinically using articulating papers and then transferred to the diagram.[6] However, this technique still involves using articulating papers.

Unlike the articulating papers and silicone inter-occlusal records, all of the previously mentioned three techniques do not mark the actual anatomical sites of contacts by themselves.

Others advocated the use of Cone Beam Computed Tomography to evaluate occlusal prematurity, however, accuracy and reproducibility were no better than other techniques. Moreover, this technique exposes the patients to needless radiation. [34]

Fuji Prescale Film (Minato, Tokyo, Japan) utilizes encapsulated ink in a pressure sensitive membrane, which is released to mark areas of contact on the film when the teeth are in contact. The film is scanned and compared with the occlusal surface of the teeth to identify size and location of contacts. The thickness of the film is considered one of this technique's limitations.[29, 35]

1.3.5 Factors Influencing Inter-Occlusal Records

The stomatognathic system involves the temporomandibular joints, in combination with the neuromuscular system, to assist the mandible in performing three-dimensional movements and guided positions, one of which is the maximum intercuspal position. The clinical intercuspal position is influenced by body posture, head position, psychological status, and time of the day. Although McLean [36] found that different body positions didn't affect the voluntary jaw movements, Coelho et. al [37] stated that different dental chair backrest inclinations would affect mandibular position, with the 180degree position (laying down flat) having the most notable effect. They recommended using 120 degrees of dental chair backrest inclination while taking inter-occlusal records, as they found no statistical differences in mandibular position at that inclination. Berry [38] assessed daily variations in occlusal contacts, the reproducibility of inter-occlusal records taken morning and evening on 3 separate days, the occlusal contacts vary throughout the day, and relies on the physical state of the masticatory systems and psychological state of the patient. Also, the number and distribution of occlusal contacts in the maximum intercuspal position vary at different levels of closing force and pressure. [39, 40]

1.4 Digital Dentistry

Recently, the use of digital dentistry and virtual images of teeth has been used more frequently in dental practice to fabricate indirect restorations. [41]

1.4.1 Intra-Oral Scanners

Intra-Oral scanners have been demonstrated to enhance diagnosis of dental conditions, facilitate treatment planning, and capture digital impressions for the fabrication of indirect

restorations.[42] Computer-aided design and computer-aided manufacturing (CAD/CAM) was introduced to dentistry in the 1980s.[43] Restorations fabricated using digital technologies are more accurate and can be fabricated quicker than using conventional techniques.[44, 45]

Generally, all CAD/CAM systems involve three main phases: acquisition phase which scans teeth; a processing phase that analyze the data to design the restoration; and a milling phase that fabricates the restoration using solid blocks of a specific dental material. [46]

Depending on the ability of various CAD/CAM systems to export data, they can be classified as being either open or closed systems. The closed systems include all the three elements exclusively, without exchanging information with other systems. Alternately, open systems offer the flexibility of working with different CAD and CAM combinations from various systems.[46]

Accuracy and precision of all CAD/CAM systems is dependent upon the data scanning technique, design software, and the specific milling unit. Data scans can either be obtained directly using intraoral scanner or indirectly using extra-oral laboratory scanner to scan either the impression or the stone cast. [47] Although the accuracy of the extra-oral scanner itself is sufficient, the possibility of inducing errors is significant due to the extra steps involved in the process due to the need for conventional impression and model fabrication. [48]

Intraoral scanning is showing considerable promise with a variety of restorations being fabricated using this technology.[46]

1.4.1.1 Advantages of Intra-Oral Scanners [49]

- Immediate evaluation of the quality of digital impression
- Ability to repeat scans easily and quickly
- Areas with inaccuracies can be cut digitally from the virtual cast and rescanned
- No impression disinfection
- Preferred by patients who have gag reflex and cannot tolerate conventional impression techniques
- Teeth preparation parameters can be evaluated thoroughly while scanning
- Virtual models are not damaged or worn while making the restoration
- Facilitates communicating with other clinicians and lab technicians
- Ability to store and retrieve data efficiently
- Saves cost associated with conventional impression
- Reduces time for clinical and laboratory procedures associated with conventional techniques
- Former digital casts can be compared with more recent ones during follow-up appointments
- Data can be fused with other virtual diagnostic records like CBCT and facial scans
- Some systems enable evaluation of color and shade matching by having true color models of dental structure and surrounding soft tissue

1.4.1.2 Disadvantages of Intra-Oral Scanners [49]

- Learning curve associated with the new technology
- Technique sensitive
- Multiple scans are often stitched together, which might be associate with some inaccuracies
- High cost associated with the initial set-up of the systems
- Extra steps are required by some systems like spraying powder to the teeth
- Some systems have larger scanning heads which makes it harder to approach posterior teeth

1.4.1.3 CEREC®

One of the earliest CAD/CAM systems with intraoral scanners introduced to dentistry was CEREC® I.[50] It was designed to operate by light triangulation, which utilizes three linear light beams that meet on one point in three dimensional space.[43] Accuracy of the virtual cast is influenced by surfaces with irregular light distribution. Therefore, a coat of opaque titanium dioxide powder is needed to provide more uniform light distribution. [51]

The CEREC® Bluecam scanner was introduced in 2009 as the 4th generation of CEREC CAD/CAM systems. Data was acquired by visible blue light emitted from an LED blue diode light source, by single image capturing. The newer version of CEREC®, AC Omnicam was introduced in 2012, using video imaging where consequent data capturing created a 3D model. While the indications for Bluecam is limited to quadrant scans and single tooth crowns; the Omnicam can be applied for full arch scans as well to fabricate accurate colored 3D models. Another advantage of the Omnicam is the powder free scanning method which is helpful with scanning larger areas of the mouth.[52]

The clinician places the camera head intra-orally with the lens towards the area of interest. The scanner head can be touching the teeth or a few millimeters away from the surface. Then it's passed over the teeth in one direction smoothly, fabricating the 3D model from the sequentially captured images. Scanning can be paused and resumed at any time by the clinician. A new feature called shake detection has been added to the system to confirm that data is only acquired while the camera is being moved in a stable motion.[46]

When scanning process is finished, the digital model can be viewed and adjusted on the screen, a virtual die identified, and the finish line outlined. Then, the software presents an ideal design for the restoration and permits the clinician to adjust it using the software's available features. Once the proposed design is accepted, the operator picks the proper block of restorative material with the selected shade and fixes it on the milling holder to produce the restoration. During the design steps, a color-coded map defines the amount of occlusal and interproximal contacts as well as proper thickness of the restorative material. Jaw relation is based on the virtual mounting obtained using a digital inter-occlusal record [53].

After scanning the preparation intraorally, the clinician can either fabricate the restoration chair-side or send the data to the central laboratory via CEREC® Connect® to design and mill the prosthesis[52]. Indications of the CEREC® system are single tooth full coverage crowns, veneers, inlays, onlays, and implant-supported fixed dental restorations [46, 54].

CEREC® is a closed system which means virtual data is only compatible with milling units supported by Sirona such as CEREC MC and CEREC In-Lab. CEREC MC is a chairside milling unit that can fabricate restorations in a single visit. Previously, CEREC MC was not indicated for milling fixed dental prostheses utilizing high-strength ceramic blocks, so those bridges had to be milled by CEREC In-Lab. With the recent improvement to the CEREC systems, CEREC MC X and CEREC MC XL in combination with CEREC® AC Omnicam provide a wider range of prosthetic options such as fixed dental prostheses and zirconia restorations.[51]

1.4.1.4 Accuracy of Intra-Oral Scanning Systems

In a study comparing digital scanners (Lava True Definition, Lava Chairside, iTero, Trios, Trios Color, Bluecam 4.0, Bluecam 4.2, Omnicam) and conventional quadrant impressions, Ender et al.[55] determined that virtual impressions had comparable accuracy to conventional impression methods. The newer scanners such as True Definition, Trios, and Trios Color were more precise than the other systems. However, the accuracy of full arch scans (Lava True Definition, Lava Chairside, iTero, Trios, Trios Color, Bluecam, Omnicam) was between the two types of conventional impressions (Polyvinyl siloxane and Alginate), and not as predictable as the quadrants intraoral scans.[56]. Another study by Patzelt et al.[57] comparing the precision of full arch scans using iTero, CEREC AC Bluecam, Lava COS and Zfx Intrascan showed that the Lava COS IO scanner had the highest precision whereas CEREC AC Bluecam had the least accuracy. Kuhr et al.[58] showed that conventional full arch impressions using polyether impression material were more accurate than full arch scans (CEREC Omnicam, 3M True Definition and TRIOS).

When assessing accuracy of intraoral scanner in fixed prosthodontics, several studies have shown promising results. Ng et al.[59] compared the marginal fit of full coverage single tooth restorations fabricated utilizing intra-oral scanning systems with those made from conventional PVS impressions and found a superior marginal fit of the crowns fabricated from the completely digital method. Zarauz et al.[60] conducted a clinical study to assess the fit of all ceramic full coverage restorations fabricated by both conventional and digital techniques on the same preparations, and found that the fit of the restorations was highly affected by the impression method utilized, with more internal and marginal misfit of the crowns made from the conventional impression technique.

For fabricating complete dentures using digital workflow, the available studies suggest that a combination of both conventional and virtual techniques are necessary.[61] Most of the available evidence regarding fabricating partial removable dental prostheses using digital technology is based on case reports, additional clinical studies are still needed.

1.4.1.5 Patients' Satisfaction

Joda et al.[62] assessed patients' satisfaction and working time utilizing intra-oral scanning systems and conventional impressions with polyether material. They found higher patient's satisfaction with the intra-oral scanning compared to the conventional impression technique. Also, the mean working time for digital scanning was 14.8 minutes whereas 17.9 minutes were required for the conventional impression technique. Another comparable cross-over study by Schepke et al.[63] compared the CEREC Omnicam with polyether conventional impression

technique, working time required for the digital scanning was 6 minutes and 39 seconds versus 12 minutes and 13 seconds for the conventional impression. More than 80% of the patients chose the digital method over the conventional one. However, the dentists concluded that the conventional impression workflow was more challenging than intraoral scanning.[64]

1.4.1.6 Virtual Occlusal Indicators

Several approaches have been recommended to allow digital representations of the patient's inter-occlusal record. Digital dental casts can be fabricated by scanning the dental casts, the impression itself, or by scanning the teeth intra-orally. Also, inter-occlusal records acquired in maximal intercuspal position (MIP), or in excursions, can be scanned and digitized. The virtual mounting of digital models can be done manually or by means of scanned inter-occlusal record. The major benefit of manually mounting the digital casts is that an inter-occlusal record is not required. Nevertheless, teeth need to be marked manually and contact locations have to be specified as references, which possibly is more time consuming than taking an inter-occlusal record. When the scanned inter-occlusal record is utilized to align the digital models, cusp indentations on the digital record are referenced to the equivalent cusps on the digital casts, eventually articulating the maxillary and mandibular digital models to each other. Then, digital contacts can be analyzed as areas on opposing digital surfaces, which are within a specified distance from each other. Inter-occlusal contact areas can also be assessed directly on the digitized inter-occlusal record using the same technique of analyzing the distance between two opposing surfaces. [10] Delong et al. found that three-dimensional digitizing techniques offer precise, quantifiable recordings of occlusal contacts when compared to trans-illumination of inter-occlusal records.[7] However, the study utilized three-dimensional commercial scanner to

digitize the casts rather than an intraoral scanner.

The thickness of any inter-occlusal recording material may affect the accuracy of the record and the bite force.[8] Also, it could interfere with the proprioceptive response, which might result in jaw deflection. Thus, the occlusal contact areas identified using recording materials do not precisely represent the natural intraoral contacts.[5, 8, 65] Forrester et al.[8] stated that T-Scan sensors which has a thickness of 96 µm and articulating paper which are 202 µm thick had considerably more consequences on the inter-occlusal record in comparison to Accufilm which is only 24 µm thick and articulating silk with thickness of 60µm. As all previously mentioned occlusal indicator techniques include placing material with some thickness between the opposing teeth during closure, the thickness of occlusal indicators remains the limitations of those tools.

An entirely virtual method with nothing placed on the occlusal surfaces during recording is available by means of intraoral scans of dental arches and buccal bite scans (virtual interocclusal records). The buccal bite scan is taken while the posterior teeth are in the maximum intercuspal position to help orient the opposing virtual arches. The system software usually creates a preliminary orientation of the casts using a least-squares computational fit, usually including measurements of the distance between two closest points on the opposing arches. [66] Ideally, when the digital casts are aligned utilizing the digital occlusal indicator, it should identify number and locations of digital occlusal contacts. While the virtual inter-occlusal records achieved from this technique are currently being utilized to make single and multiple-unit prostheses, evidence of precision and reproducibility of this process is lacking.

Solaberrieta et al.[9] conducted a study to evaluate the accuracy of digital inter-occlusal records. They were able to show that the digital inter-occlusal record is a valid technique for orienting the mandibular cast and that contact points obtained by the digital method were significantly more precise than the ones obtained by the conventional method. However, this study utilized an industrial three-dimensional extra-oral scanner to scan the models and digitize the inter-occlusal records, thus, the findings cannot be applied to clinical use of intra-oral scanners.

Stavness et al.[67] utilized an intra-oral scanner to scan maxillary and mandibular models, as well as an industrial three-dimensional extra-oral scanner to acquire the virtual inter-occlusal records. They stated that digital simulation utilizing virtual inter-occlusal records can closely reproduce the patients' occlusion of mounted models on a conventional semi-adjustable articulator. Nevertheless, this was an in-vitro study and involved digitizing the casts with an extra-oral scanner rather than an intra-oral one.

Solaberrieta et al.[68, 69] concluded that intra-oral digital inter-occlusal record is a valid method for orienting a mandibular cast on a virtual articulator. Contacts obtained by virtual methods were compared to contacts identified on the casts utilizing the conventional methods of articulating ribbon and shimstock foil. An industrial three-dimensional scanner and two intra-oral scanners (3M Lava Cos and Trios 3Shape) were utilized. The most accurate virtual inter-occlusal records were acquired by a combination of two lateral and one frontal scans, or a combination of left and right lateral inter-occlusal records. The best outcome was obtained when the distance between the sections was increased. Results of this in-vitro study should be interpreted carefully with respect to clinical application.

Iwaki et al.[70] evaluated the dimensional precision of digital inter-occlusal records utilizing CEREC Bluecam intra-oral scanning system compared to silicone inter-occlusal records in-vitro. They identified specific reference points on the casts and measured the distances and angles between them for both digital and physical inter-occlusal records before and after teeth preparations. They concluded that the digital inter-occlusal record was more accurate for the fabrication of single tooth posterior crowns in comparison to the conventional technique, nevertheless, for multiple unit restorations, the intraoral scanner had significantly more errors.

Another study by Arslan et al. evaluated the accuracy of the newer CEREC intra-oral scanner, the Omnicam, in identifying the occlusal contacts on a dental cast.[71] They assessed the precision of digitally identified occlusal contacts by comparing it to the ones recognized by articulating paper on the same casts. The variables evaluated were full arch and half arch intraoral scans, prepared abutment teeth and sound teeth, and buccal bite scans acquired on the same side compared to the ones taken at the contralateral side. They superimposed the screenshot images of the virtual inter-occlusal record on the screenshots images of the casts with the conventionally indicated occlusal contacts. The highest percentages of agreement between virtual and conventional occlusal contacts were found with full arch impressions of non-prepared teeth. No significant difference was found between scanning prepared and non-prepared abutments with full-arch scans, irrespective of the location of the buccal bite scans. On the other hand, scanning non-prepared teeth with half arch impressions showed significantly less percentage of agreement between the conventional and digital methods than full arch scans of non-prepared teeth. Consequently, they suggested taking a full-arch scan when there is no

posterior antagonist contact after tooth preparations. Although they've used CEREC Omnicam intraoral scanning system, the study was done on study casts rather than natural teeth.

A more recent study by Edher [72] assessed the effect of buccal bite scan location on the alignment of the virtual casts, and evaluated if quadrant scans and full arch scans have an influence on the alignment of the virtual casts. They found that the location of the buccal bite scan affected the virtual casts alignment especially with full arch scans. Also, quadrant scans were articulated more accurately than full arch scans using virtual inter-occlusal records. Consequently, they recommended taking quadrant scans for restorative work and in case of the need for full arch scan, buccal bite scan should be as close as possible to the area of interest.

No clinical studies have been undertaken to evaluate the occlusion generated from intraoral scanners directly in the mouth, most of them have used laboratory scanners or intraoral scanners for dental casts.

1.5 Literature Review Summary

When it comes to determining inter-occlusal contacts, a variety of occlusal indicators have been used in the past. Clinically, the precision of most occlusal contact recording methods is lacking. All the previously mentioned inter-occlusal record techniques should be considered as supplementary documentation strategies, as they have no proven consistency or validity, and their effectiveness is not well supported by evidence.[5, 7, 73] The new digital scanning techniques show occlusal diagnostic potential, but they require validation.[18, 73]

Intraoral digital scanning systems are now being broadly in use in dental practice, allowing the prosthetic reconstruction to be completely digitized. Though conventional impression method and materials are well supported by evidence and are known for their high precision, intra-oral scanning has the benefits of saving time and material, and increase work efficiency.

Intra-oral scanning systems fabricate virtual casts and orient them for digital articulation to be utilized in fabricating restorations. Digital models are mounted by the means of virtual inter-occlusal records taken with an intra-oral scanner. There is a lack of available evidence on the validity of this process, and limited recommendations on the most efficient technique to obtain an accurate registration of occlusal contacts.

1.6 Study Rationale

Digital dentistry has been increasingly incorporated into clinical dental practice and is replacing many conventional techniques, one of which is the inter-occlusal record. While several studies have investigated the accuracy of virtual inter-occlusal records obtained with an extra-oral scanners in-vitro, no clinical studies utilizing virtual in-vivo inter-occlusal records have been published to date. Consequently, this clinical study was designed to evaluate the use of an intraoral scanning system to virtually articulate dental casts.

1.7 Aims

The aims of this study were:

- To evaluate the clinical accuracy of virtual inter-occlusal records of an intraoral scanning system by comparing the presence or absence of sites of close proximity (SCP) and sites of clearance (SC) on a virtual inter-occlusal record taken with CEREC Omnicam intraoral scanning system to the conventional inter-occlusal record taken with silicone (PVS) material.
- To evaluate reproducibility of virtual inter-occlusal records of an intraoral scanning system by clinically comparing the presence or absence of sites of close proximity (SCP) and sites of clearance (SC) on multiple virtual inter-occlusal records taken with CEREC Omnicam intraoral scanning systems.

1.8 Hypotheses

- Virtual inter-occlusal records obtained by CEREC Omnicam intraoral scanning system are able to identify the same SCP and SC identified by the conventional inter-occlusal record taken with PVS material.
- Multiple virtual inter-occlusal records obtained by CEREC Omnicam intraoral scanning system are able to identify the same SCP and SC consistently.

Chapter 2: Materials and Methods

Virtual inter-occlusal records taken with CEREC Omnicam intraoral scanning system were compared to the conventional inter-occlusal records obtained with PVS material, which was considered as the gold standard in the current study. Accuracy of the virtual inter-occlusal record as well as reproducibility were tested in order to provide evidence for clinicians regarding the suitability of intraoral scanners in recording inter-occlusal records to fabricate dental restorations with proper inter-occlusal relationship.

2.1 Sample Size

Sixty virtually articulated casts were obtained from ten participants. They resulted from three virtual inter-occlusal records per side per participants (3x2x10=60). Also, sixty sites of close proximity (SCP) and sixty sites of clearance (SC) were obtained by identifying three SCP per side per participant and three SC per side per participant (3x2x10=60). This provided an adequate number of SCP and SC for a clinically valid comparison.

2.2 Sample Recruitment

Posters explaining the research were placed on notice boards within the UBC Faculty of Dentistry building. Young adults (20-40 years old), dentate with minimum of 24 teeth were invited to participate. A $20 gift card was provided an additional incentive to participate. A consent form was developed by the investigator and signed by the participants (Appendix A).

Ethics certificate of expedite approval (UBC CREB NUMBER: H17-00192) was obtained from the clinical research ethics board at the office of research office, UBC on April 12, 2017.

2.3 Inter-occlusal Record

Inter-occlusal records from 10 participants were taken for right and left sides independently. Chair position was standardized for all patients at 120 degrees of head tilt. Patients received the same verbal instructions to rehearse the position of MIP three times before the definitive recording. An inter-occlusal record for each side was taken with a Polyvinyl Siloxane (PVS) material (Futar D, Kettenbach GmbH & Co., Germany) **(Figure 1).**

Figure 1 Conventional PVS Inter-Occlusal Record

2.4 Virtual Casts

Each participant was assigned an identification number to maintain subject confidentiality. A mandibular first molar on each side was selected as a prepared tooth and an e.max crown was entered as the planned restoration using the CEREC® Omnicam intra-oral scanner software (Dentsply Sirona, USA). Then, right and left quadrant scans were performed and saved independently. The maxillary and mandibular quadrant scans for each side remained constant while three buccal bite scans were repeated and saved independently. All three repetitions were made using the same scanning protocol. As a result, 60 virtual mounted casts were produced and saved with unique identification numbers.

2.5 Trans-illumination

Sites of close proximity (SCP) were identified where the distance between the two arches is ≤100 µm, whereas sites of clearance (SC) were identified where the distance between the two arches is >100 µm. The SCP & SC were both identified by trans-illuminating the three PVS bite registrations using the methodology of previous research [2, 74]. Calibration molds were made from the same material by injecting it between two glass plates along with a calibrated metal ring of a known thickness of 100 µm (Bearings Canada Inc, Canada). For each inter-occlusal record, the three bite registrations with the calibrated molds were placed on a flat light box and imaged with Nikon SLR Camera. Camera settings were set on the manual mode without flash for all images. Distance between the camera and the object being imaged was always set to be 30 inches. Images were saved as JPEG format with size of 2 MB.

The digital images were then uploaded on ImageJ software to further analyze them. ImageJ 1.46 is an image processing software that was developed to display, edit, analyze, process, save, and

greyscale and colored images.[75] The images were then converted from colored to grey scale, and the pixel value for the mold was calibrated to 100 µm. The ImageJ software can detect any areas of PVS material with 100 µm thickness and identifying it as red. **(Figure 2-3)**

Sites of close proximity (SCP) were identified on anatomical landmarks where the distance between the two arches is ≤100 µm. Three anatomical landmarks per side per participant were marked as SCP if they were identified on the three repetitions of PVS inter-occlusal records as red. On the other hand, sites of clearance (SC) were identified on anatomical landmarks where the distance between the two arches is >100 µm. Three anatomical landmarks per side per participant were marked as SC if they appear in grey, which indicates that cusps are close to each other but still >100 µm, on the three repetitions of PVS inter-occlusal records. The SCP and SC were only considered to be reference points on the conventional inter-occlusal record method if they were existent on the three repeated PVS inter-occlusal records. This allowed for identifying the reference points with a degree of confidence.

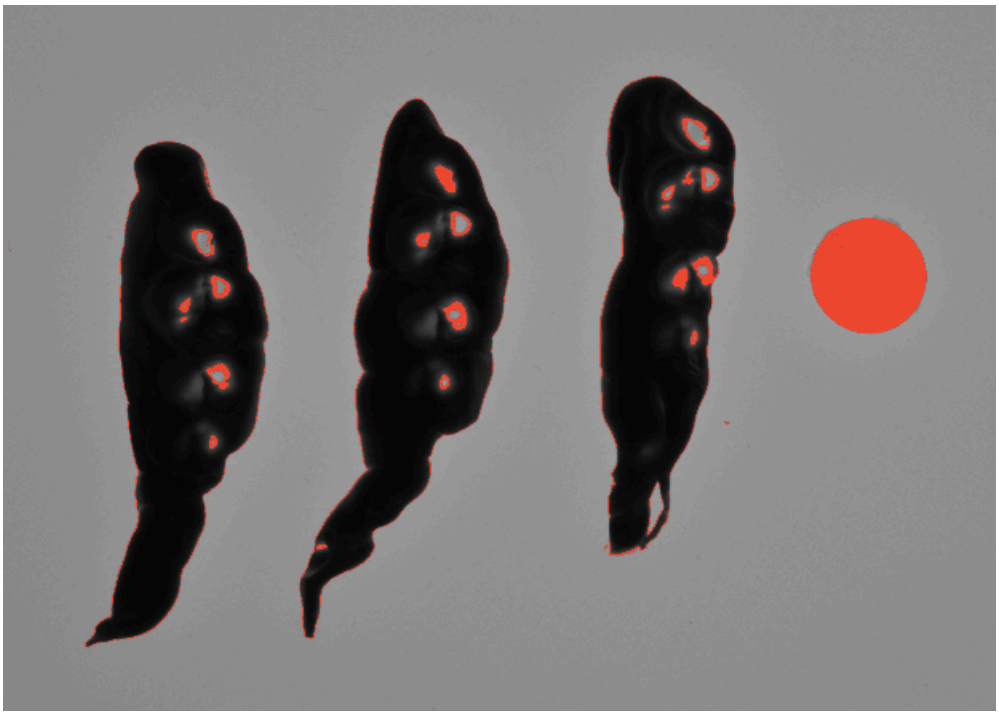


Figure 2 Three trans-illuminated inter-occlusal records for left bite of participant #1 (LB1) with the calibration mold

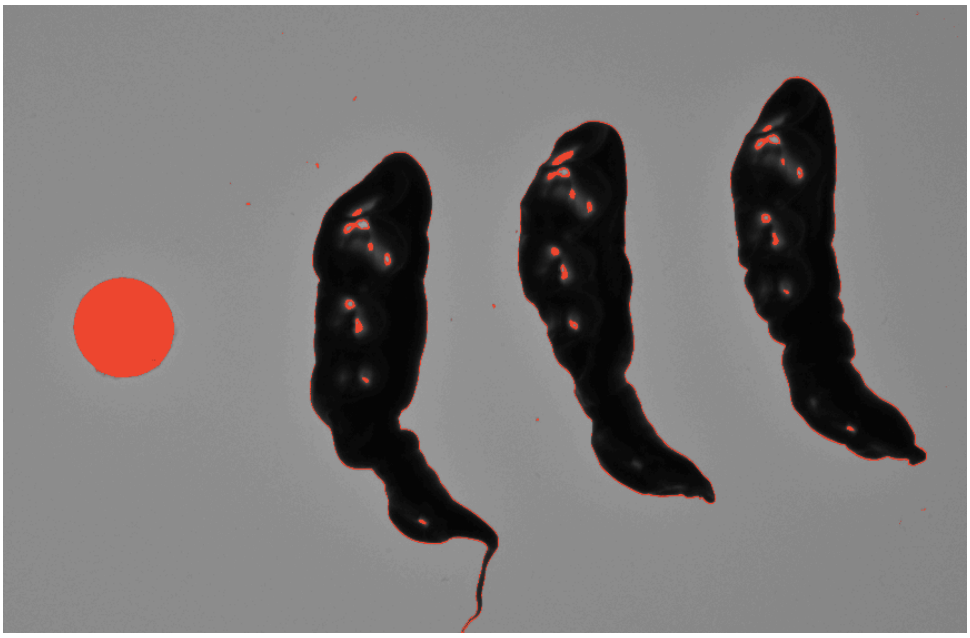


Figure 3 Three trans-illuminated inter-occlusal records for the right bite of participant #1 (RB1) with the calibrated mold

2.6 Virtual Cast Analysis

Since CEREC is a closed system, all virtual dental casts were sent to a CEREC specialist at Patterson Dental via the Sirona Connect Portal (DENTSPLY Sirona, USA) to be converted into Standard Tessellation Language (.stl) file format. CloudCompare V2.7 was then utilized to further analyze the degree of separation between the points on the virtual casts. This three-dimensional point cloud processing software works with triangular meshes and point clouds by measuring the distance between a point-cloud on an occlusal surface of one virtual cast and the closest mesh on the occlusal surface of the opposing arch. [66] The default state of CloudCompare provides measurement of the "nearest neighbor" distances between two point-clouds. These distances can be signed to distinguish between mesh-separations and mesh-penetrations, and displayed to any specified ranges and resolutions. Hence, it has the advantage of being able to set the cutoff of any distance to identify sites of close proximity. In the current study, it was set to show distances ≤100 μm.

The CEREC articulated casts were imported into the CloudCompare system and measurements between the two opposing arches were made. A threshold was set for the program distance map to display the points with distances of ≤100 μm, which identified the sites of close proximity. Light green represents areas with 0 to +100 μm, while dark green represents areas with -1 to -100 μm or perforations. Grey color represents sites of clearance with a distance of >100 μm. **(Figure 4-5)**

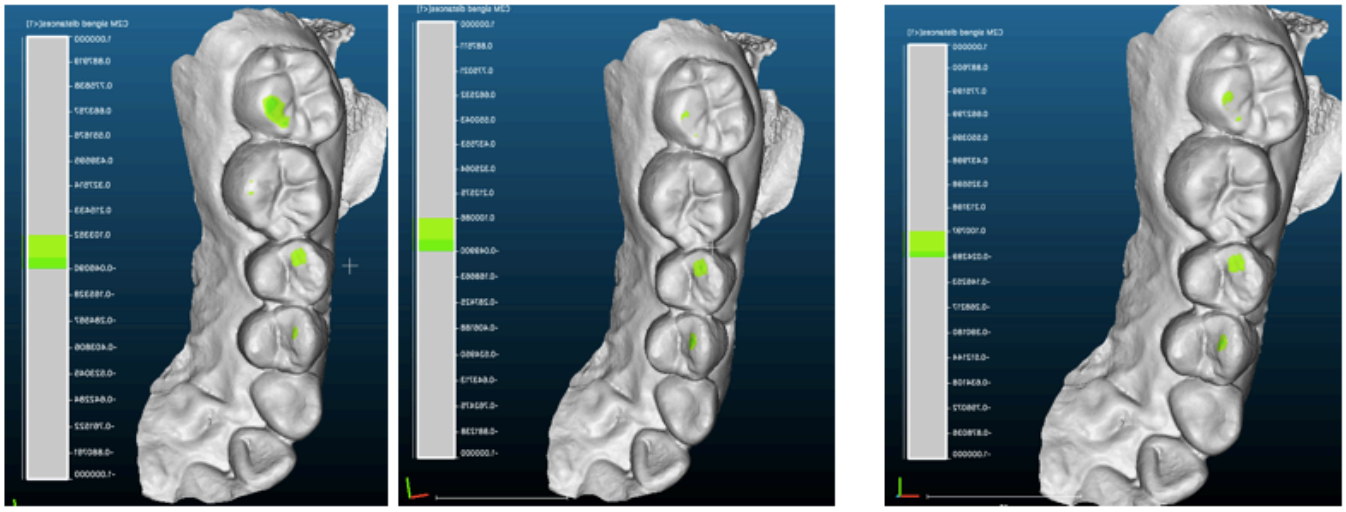


Figure 4 Three different virtual inter-occlusal records for left side of participant #1 (LB1)

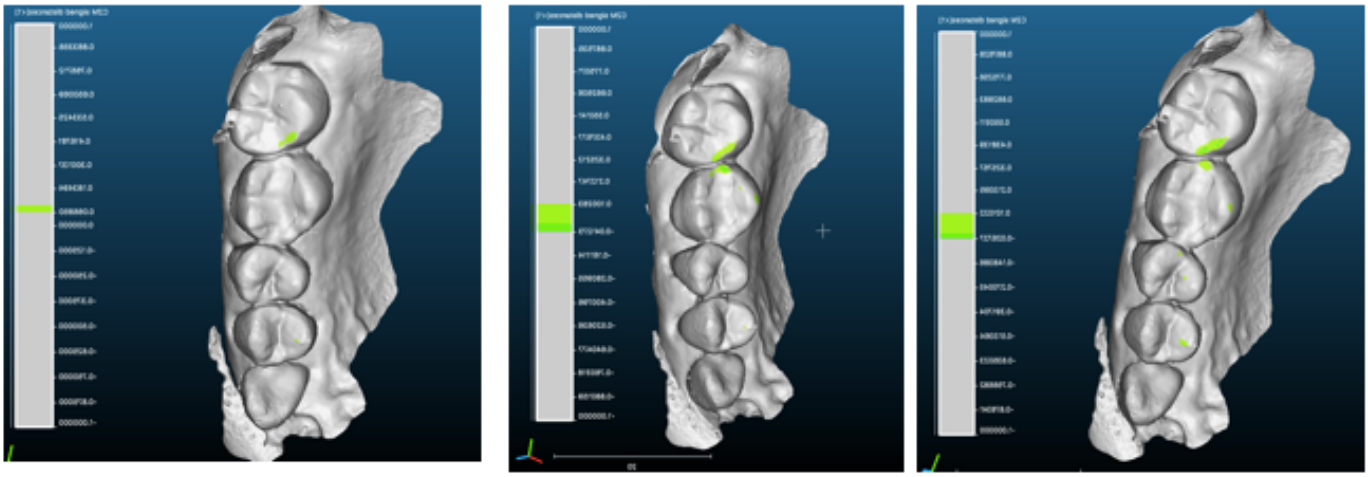
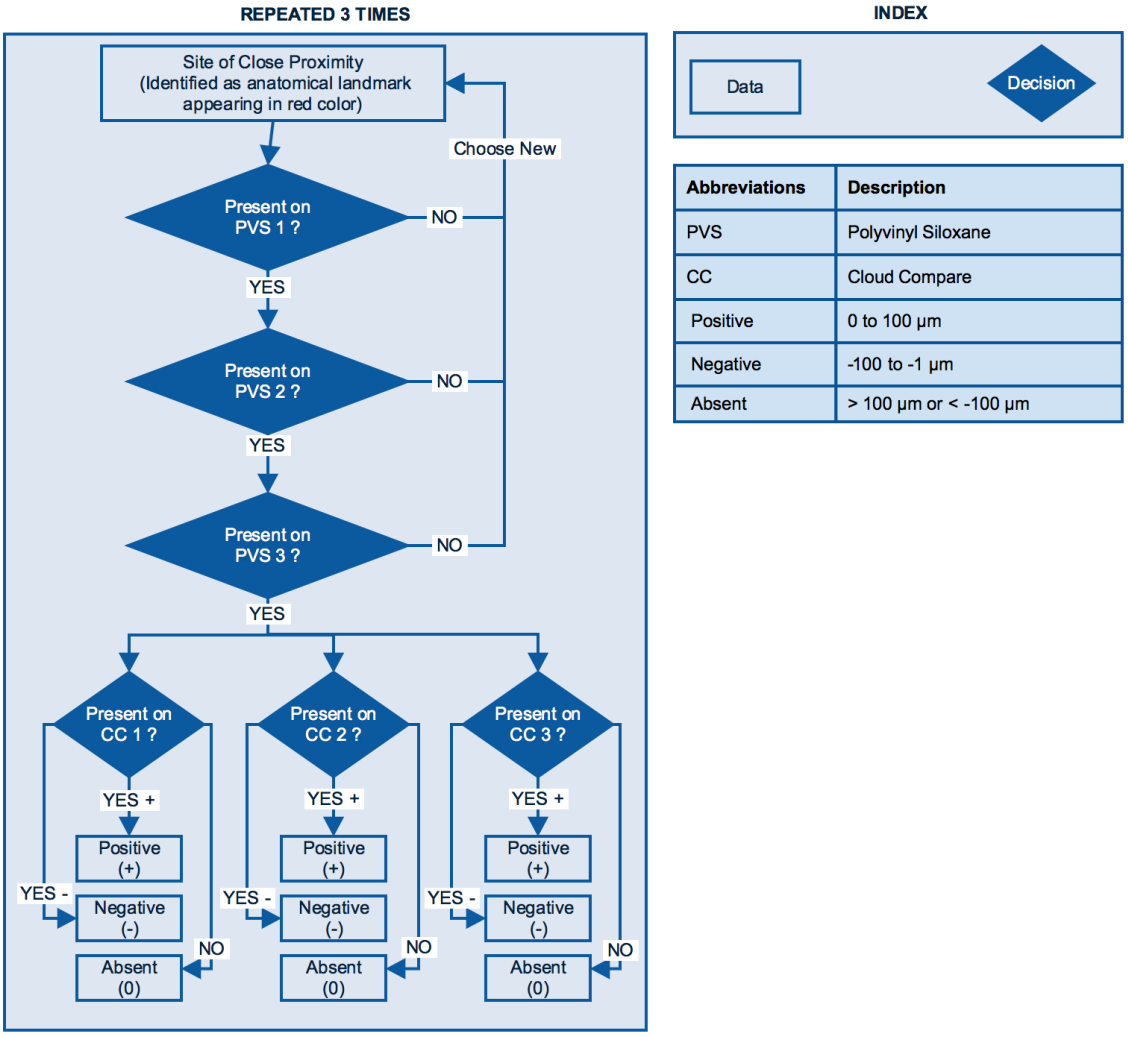


Figure 5 Three different virtual inter-occlusal records for right side of participant #1 (RB1)

2.7 Identifying Sites of Close Proximity and Sites of Clearance

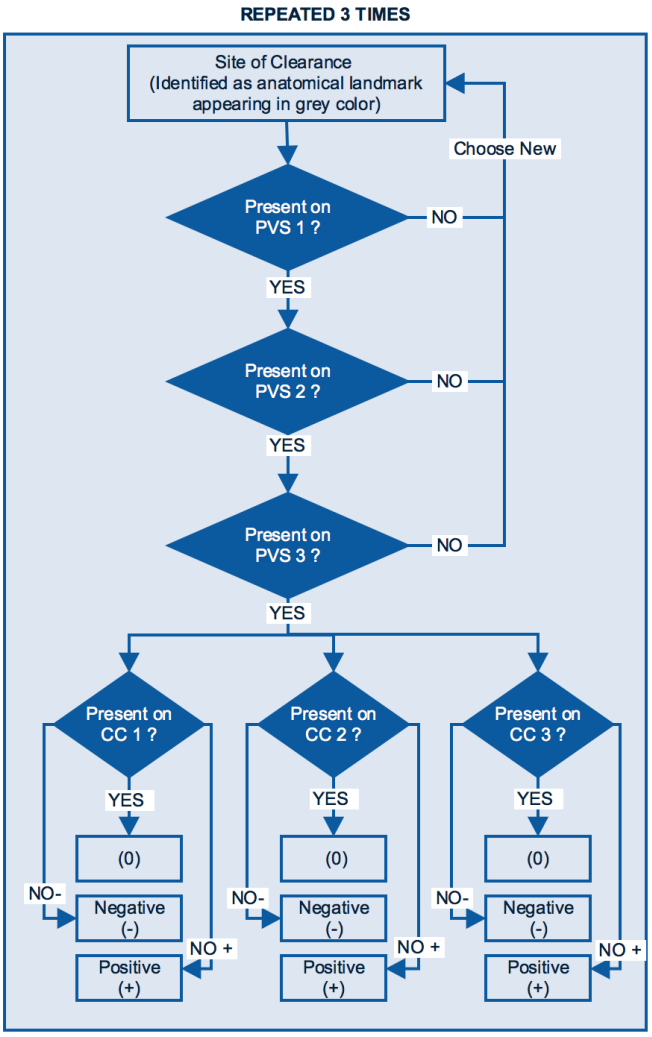
Three anatomical landmarks per side per participant were identified as SCP for a total of six SCP per participant. The CloudCompare software was used to determine the presence or absence of contacts on the same anatomical landmarks on the virtual casts. Also, SC were identified by choosing three anatomical landmarks per side per participant where they appear in grey on the three PVS inter-occlusal records. The presence or absence of these SC were confirmed on the same anatomical landmarks on the virtual casts. The process of identifying SCP and SC is illustrated in **Figure 6** and **Figure 7**.

A total of sixty SCP were identified for ten participants as well as sixty SC identified with the PVS inter-occlusal record (gold standard) were compared with the SCP and SC generated from the CEREC software.



Abbreviations	Description
PVS	Polyvinyl Siloxane
CC	Cloud Compare
Positive	0 to 100 µm
Negative	-100 to -1 µm
Absent	> 100 µm or < -100 µm

Figure 6 A decision map illustrating the process of identifying SCP on the conventional inter-occlusal records and comparing it with the virtual inter-occlusal records



Abbreviations	Description
PVS	Polyvinyl Siloxane
CC	Cloud Compare
Positive (+)	0 to 100 µm
Negative (-)	-100 to -1 µm
(0)	> 100 µm or < -100 µm

Figure 7 A decision map illustrating the process of identifying SC on the conventional inter-occlusal records and comparing it with the virtual inter-occlusal records

2.8 Comparison and Statistical Analysis

The conventional silicone inter-occlusal records were used as the gold standard in this study. After analyzing the images of the trans-illuminated inter-occlusal records, three landmarks per side per participant were identified as the reference points for comparing the virtual inter-occlusal records. To validate the comparison, a contact point is chosen as a reference landmark if it's existent on the three silicone inter-occlusal material. This resulted in 60 identified landmarks as the reference points for the sites of close proximity with material thickness of 0-100 microns **(Figures 8-27)**.

Each landmark was compared on the virtual inter-occlusal records and identified as:

- (0) Absent Contacts > 100 µm
- (+) Present contacts, positive 0 to 100 µm
- (-) Present contacts, negative -1 to -100 µm

The same protocol was used to identify sites of clearance: three landmarks were identified per side per participant and compared to the virtual inter-occlusal records:

- (0) Sites of Clearance
- (+) Contacts range between -100 µm to + 100 µm

For accuracy analysis, True positive (TP), true negative (TN), false positive (FP), and false negative (FN) calculations were made for each virtual inter-occlusal record taken, and consequently the sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were calculated in a way similar to other studies by Delong et al.[76] and Solaberrieta et al.[68, 69]

Sensitivity is defined as the ability of the virtual scan to identify contacts when they are actually existent; Sensitivity =TP/(TP+FN).

Specificity is the ability of the virtual inter-occlusal record to identify sites of clearance when there are no contacts on the conventional inter-occlusal record; Specificity = TP/(TP+FP).

PPV indicates the likelihood a contact actually exists when the outcome is positive; PPV = TP / (TP+FP)

NPV indicates the possibility of a contact being absent when the test is negative; NPV = TN / (TN+FN)

For reproducibility, different scenarios were made to calculate the agreement between the three different scans and to assess reproducibility of the virtual inter-occlusal record.

1 Left

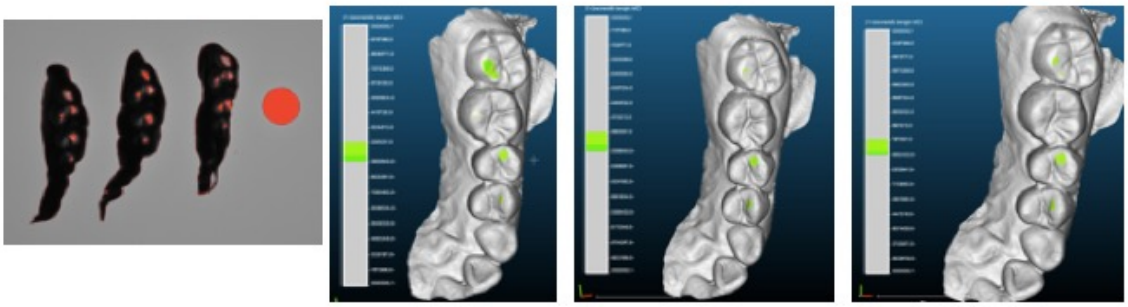


Figure 8 Conventional and virtual inter-occlusal records for left side of participant #1 (LB1)

1 Right

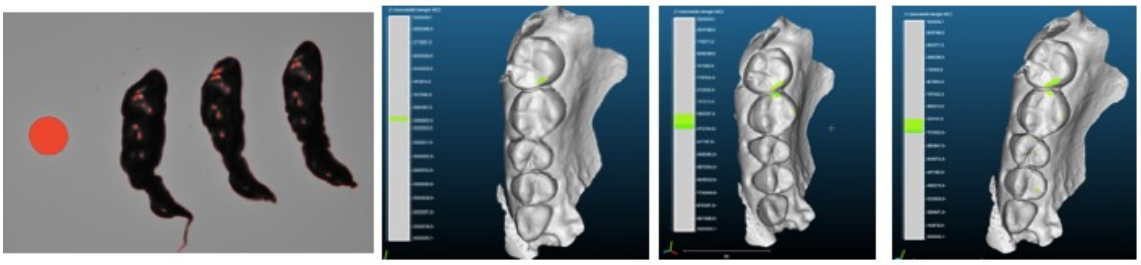


Figure 9 Conventional and virtual inter-occlusal records for right side of participant #1 (RB1)

2 left

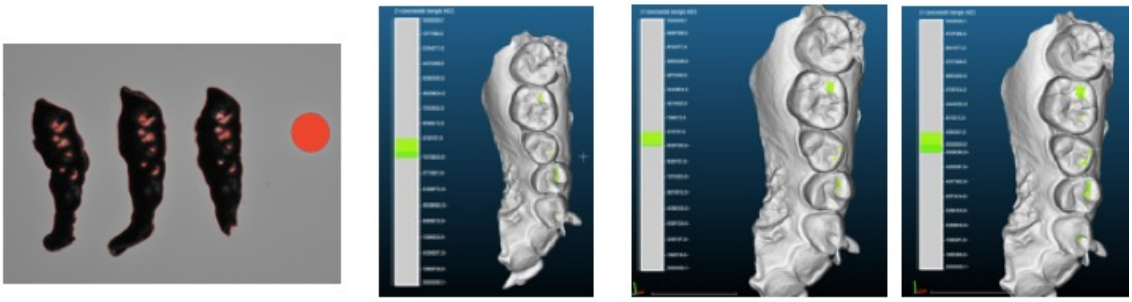


Figure 10 Conventional and virtual inter-occlusal records for left side of participant #2 (LB2)

2 right

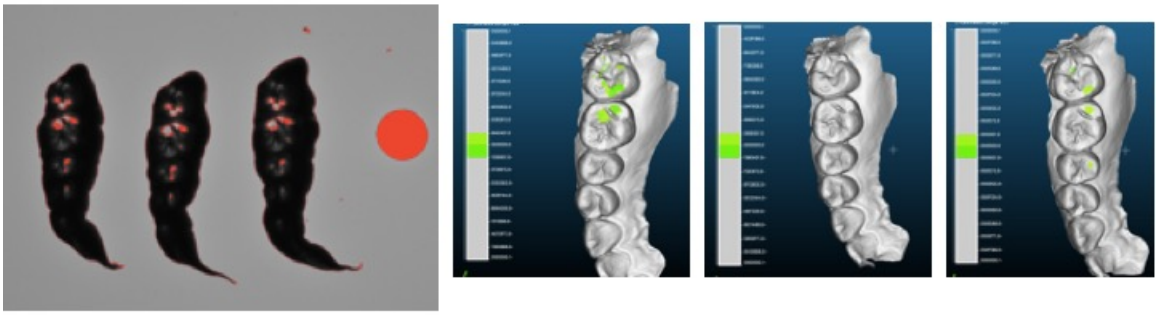


Figure 11 Conventional and virtual inter-occlusal records for right side of participant #2 (RB2)

3 left

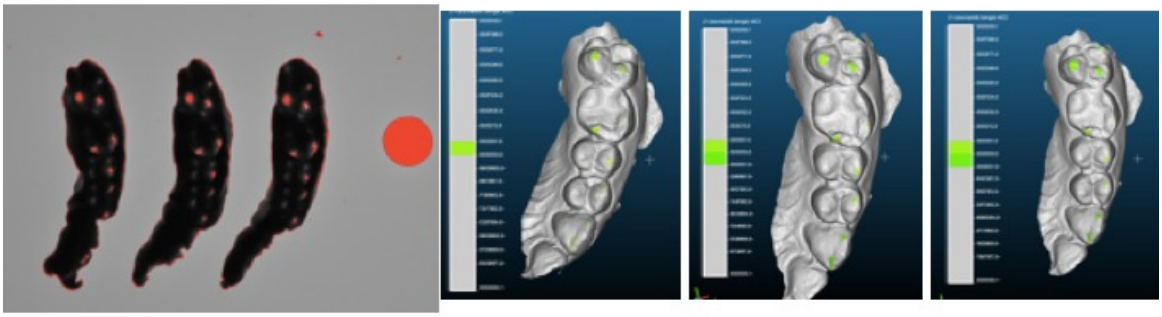


Figure 12 Conventional and virtual inter-occlusal records for left side of participant #3 (LB3)

3 right

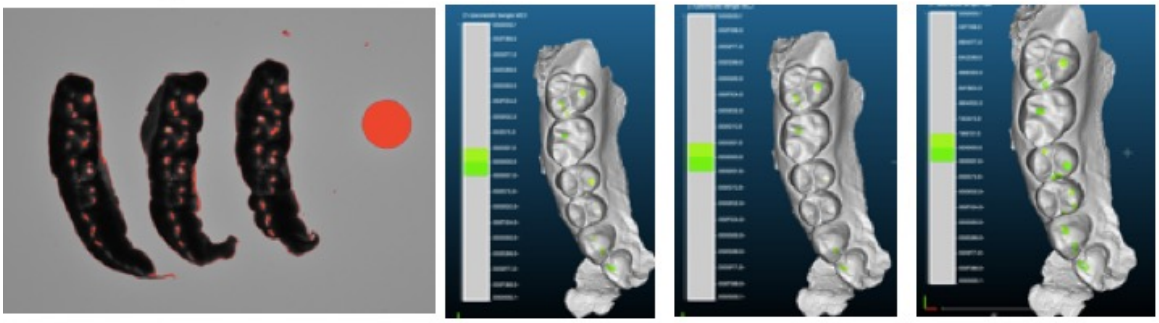


Figure 13 Conventional and virtual inter-occlusal records for right side of participant #3 (RB3)

4 left

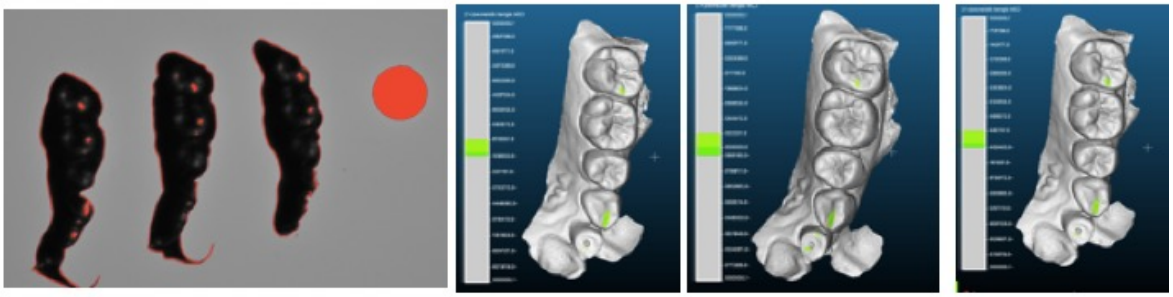


Figure 14 Conventional and virtual inter-occlusal records for left side of participant #4 (LB4)

4 right

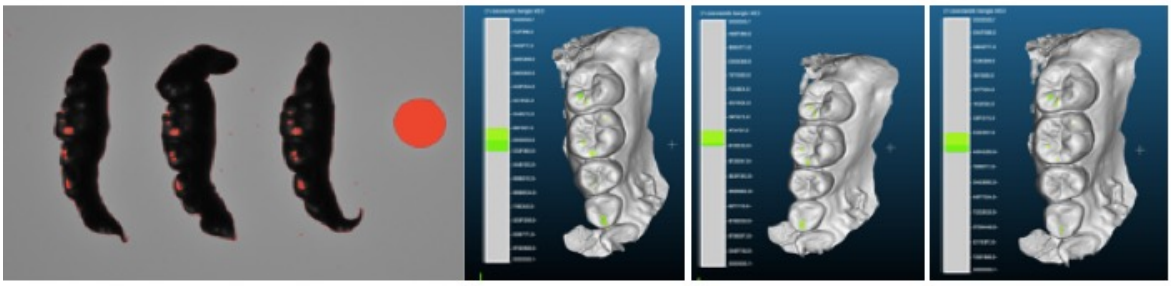


Figure 15 Conventional and virtual inter-occlusal records for right side of participant #4 (RB4)

5 left

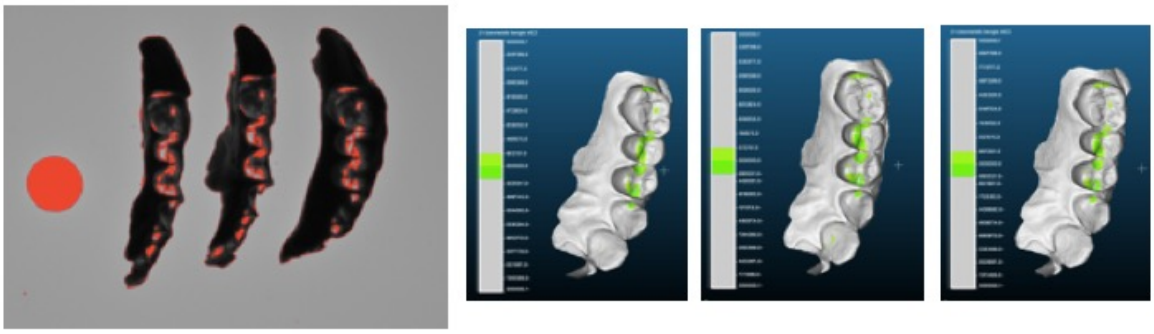


Figure 16 Conventional and virtual inter-occlusal for left side of participant #5 (LB5)

5 right

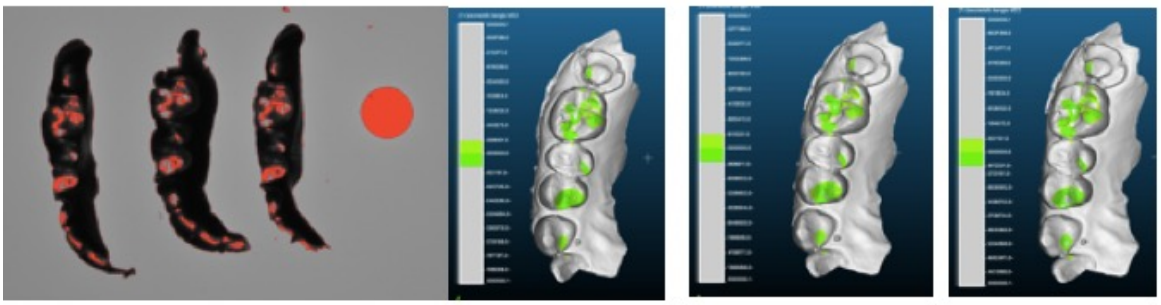


Figure 17 Conventional and virtual inter-occlusal records for right side of participant #5 (RB5)

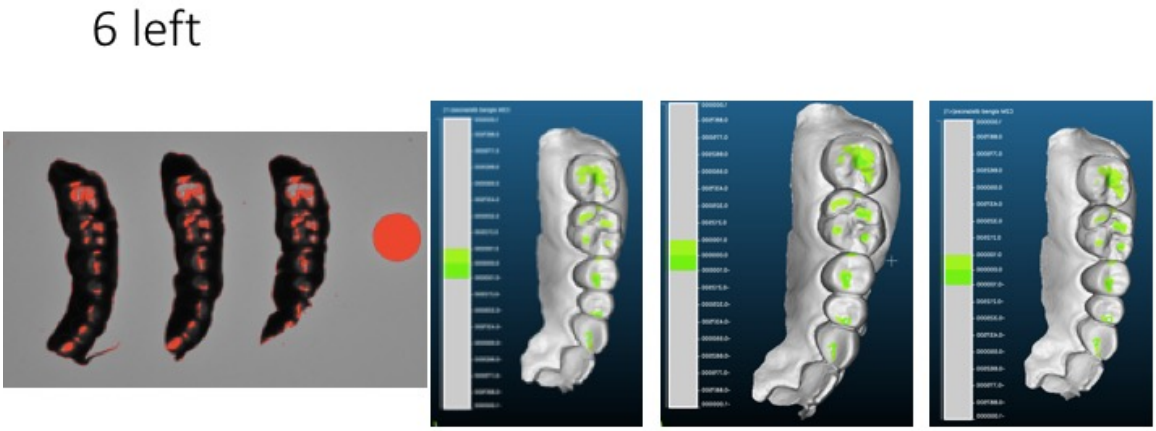


Figure 18 Conventional and virtual inter-occlusal records for left side of participant #6 (LB6)

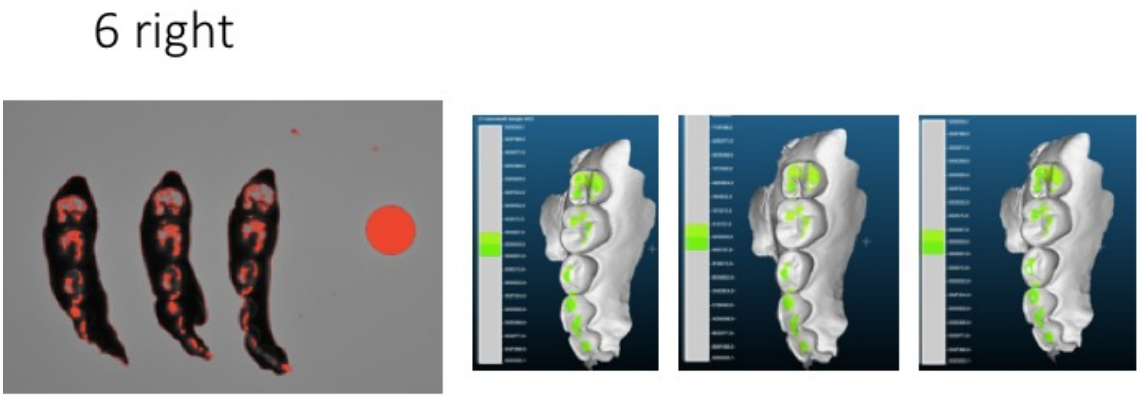


Figure 19 Conventional and virtual inter-occlusal for right side of participant #6 (RB6)

7 left

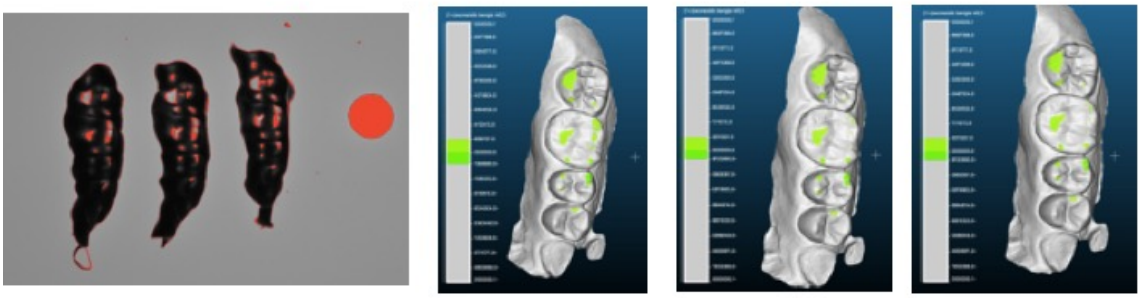


Figure 20 Conventional and virtual inter-occlusal records for left side of participant #7 (LB7)

7 Right

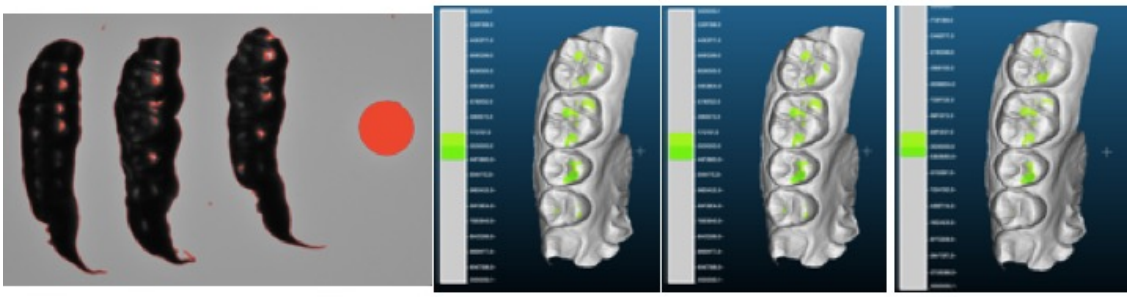


Figure 21 Conventional and virtual inter-occlusal records for right side of participant #7 (RB7)

8 left

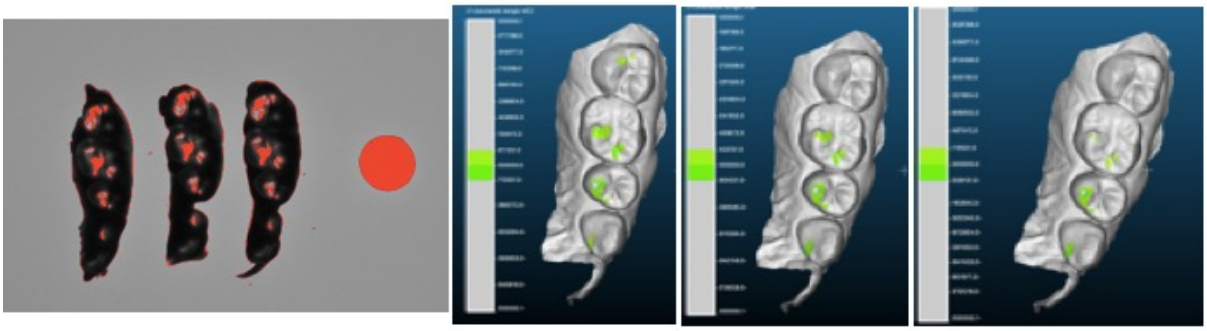


Figure 22 Conventional and virtual inter-occlusal records for left side of participant #8 (LB8)

8 right

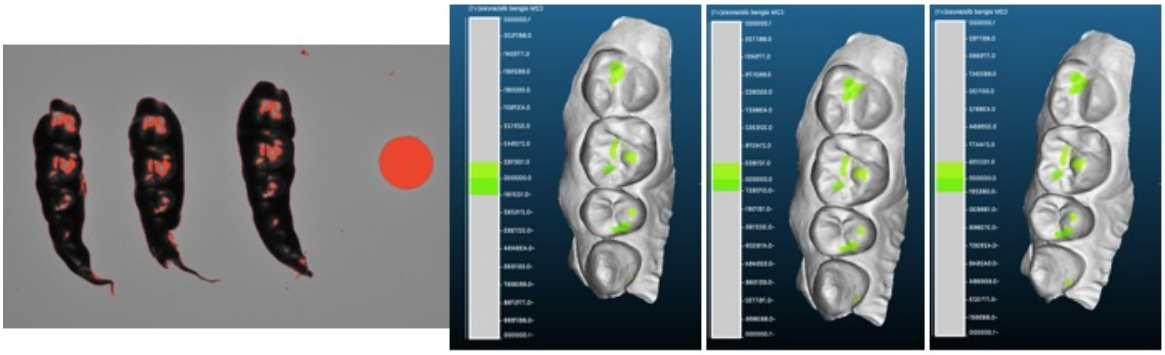


Figure 23 Conventional and virtual inter-occlusal records for right side of participant #8 (LB8)

9 left

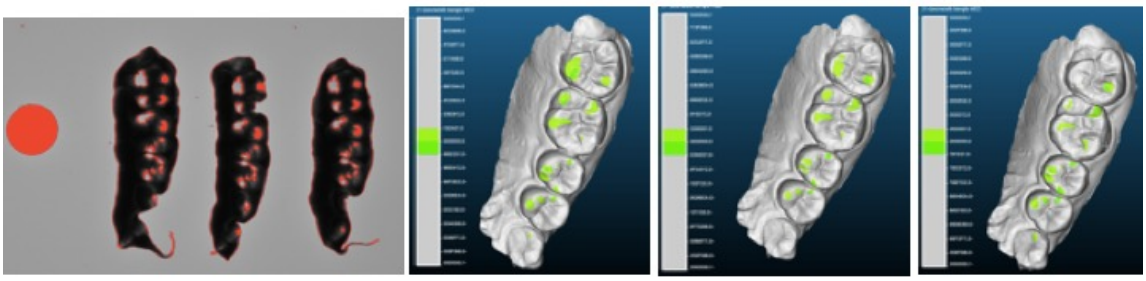


Figure 24 Conventional and virtual inter-occlusal records for left side of participant #9 (LB9)

9 right

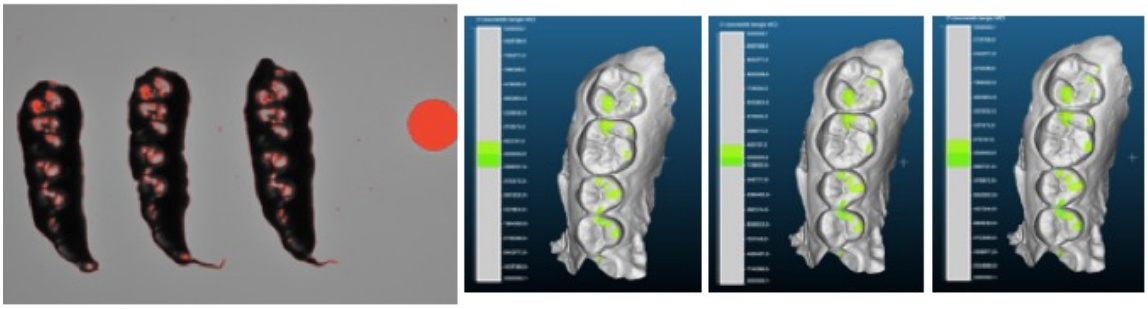


Figure 25 Conventional and virtual inter-occlusal records for right side of participant #9 (RB9)

10 left

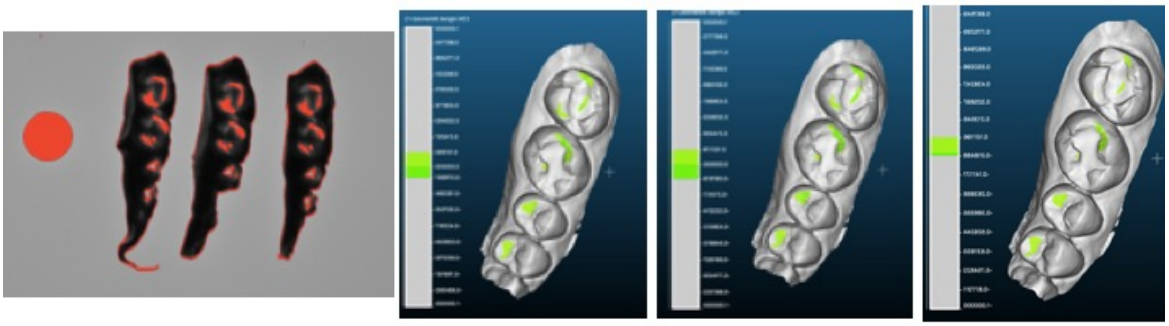


Figure 26 Conventional and virtual inter-occlusal records for left side of participant #10 (LB10)

10 right

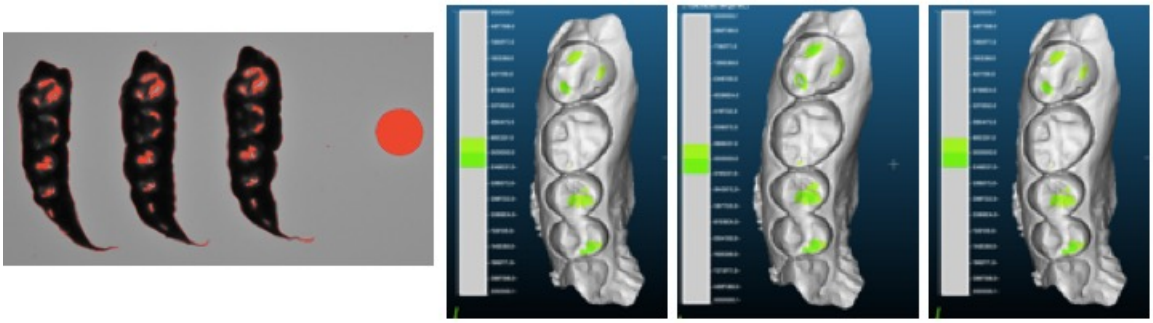


Figure 27 Conventional and virtual inter-occlusal records for right side of participant #10 (RB10)

Chapter 3: Results

2.9 Accuracy and Reproducibility analysis

A total of three different virtual inter-occlusal records were obtained for each side per participant. The sites of close proximity and sites of clearance are listed in **Tables 1 & 2** along with the variability in detecting the contacts with the three different scans. The accuracy of the 3 interocclusal records are listed in **Tables 3, 4 & 5**. The true positive, true negative, false positive, and false negative sites were identified for each virtual inter-occlusal record. The sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) are all listed.

Sensitivity for the three different scans was 87%, 82% and 85% with the highest value for the first scan. On the other hand, specificity was higher with values of 95%, 97% and 93%. Positive predictive values for the three scans were 95%, 96%, and 93%; whereas, the negative predictive values were respectively 84%, 86% and 88%.

The reliability of the virtual inter-occlusal record using the three scans to identify landmarks for both sites of proximity and sites of clearance were listed in **Tables 6** & **7.** Percentage agreement was calculated for the 60 landmarks. For sites of close proximity detection, 74% of the landmarks were detected with all three scans correctly while 7% of them were not detected at all. Thirteen percent of the landmarks were identified by two scans out of three and only 7% of the landmarks were detected in one scan out of the three repetitions (**Figure 28).**

When the same analysis was done for sites of clearance, 92% of the landmarks were identified as sites of clearance accurately with all the three scans. Only one landmark (2%) was detected as a site of close proximity instead of clearance in all of the three scans. Three percent of the

landmarks were detected accurately twice and 3% of them were only identified once. **(Figure 29)**

Sites of close proximity analysis of the virtual inter-occlusal record identified some of the contact areas as perforations through the opposing dental arch rather than positive contacts. CloudCompare identified that 22% of the sites of close proximity were perforations instead of positive site of close proximity in all three virtual inter-occlusal records. Another 20% of them were marked as perforations in one scan and 10% in two scans out of the three repetitions. **(Figure 30)**

Table 1 Sites of close proximity analysis

Sample	Landmarks	CC 1	CC2	CC3
LB1	#27MP	-	+	+
	#26DB	0	0	0
	#25B	+	+	+
RB1	#16D	0	-	+
	#16P	0	+	+
	#15D	0	0	+
LB2	#26DB	+	+	-
	#26MB	0	0	+
	#25B	+	+	-
RB2	#17M	-	0	+
	#16MP	-	0	+
	#16MB	+	0	0
LB3	#27P	+	+	-
	#26MB	+	+	+
	#25B	-	+	+
RB3	#17P	+	-	-
	#15P	+	+	-
	#14DP	+	0	+
LB4	#27MB	+	+	+
	#26B	0	0	0
	#24	+	+	+
RB4	#16 M	+	+	+
	#15MB	+	+	+
	#13M	-	+	+
LB5	#26DB	-	-	+
	#25MP	-	-	-
	#24 M	-	-	-
RB5	#16MB	-	-	+
	#16MP	-	-	-
	#14M	-	-	-

Abbreviations

LB: Left Bite

RB: Right Bite

M: Mesial

MP: Mesiopalatal

MB: Mesiobuccal

D: Distal

DB: Distobuccal

DP: Distopalatal

P: Palatal

B: Buccal

Sample	Landmarks	CC 1	CC2	CC3
LB6	#27D	-	-	-
	#26MB	+	-	-
	#24M	-	-	-
RB6	#17MB	-	+	-
	#16DB	-	+	-
	#15B	-	-	-
LB7	#27P	+	+	+
	#26DB	+	+	+
	#26P	+	+	+
RB7	#17DP	+	+	0
	#17MP	+	+	+
	#16DP	+	+	+
LB8	#27P	+	0	0
	#26DP	0	0	0
	#25P	-	-	-
RB8	#17D	-	-	-
	#16MP	+	+	+
	#15P	+	+	+
LB9	#27MP	-	+	0
	#26DP	-	+	+
	#25D	-	-	-
RB9	#17MP	-	-	-
	#16DP	+	+	+
	#15P	+	+	+
LB10	#27MP	+	+	0
	#26D	-	-	-
	#25P	+	-	+
RB10	#17MP	+	+	+
	#16MP	0	0	0
	#15B	-	-	-

Table 2 Sites of clearance analysis

Sample	Landmarks	CC 1	CC2	CC3
LB1	#26MB	0	0	0
	#24L	0	0	0
	#25L	0	0	0
RB1	#16DB	0	0	0
	#15B	0	0	0
	#14B	0	0	0
LB2	#26MP	0	0	0
	#24B	+	+	+
	#24P	0	0	0
RB2	#16MB	0	0	+
	#14B	0	0	+
	#17DB	+	0	+
LB3	#26DP	0	0	0
	#25P	0	0	0
	#24P	0	0	0
RB3	#17DB	0	0	0
	#14B	0	0	0
	#16D	0	0	0
LB4	#27MP	0	0	0
	#26DP	0	0	0
	#25B	0	0	0
RB4	#17P	0	0	0
	#16MP	0	0	0
	#15P	0	0	0
LB5	#26MB	0	0	0
	#25B	0	0	0
	#24 CENTRE	0	0	0
RB5	#15B	0	0	0
	#14D	0	0	0
	#16DB	0	0	0

Abbreviations

LB: Left Bite

RB: Right Bite

M: Mesial

MP: Mesiopalatal

MB: Mesiobuccal

D: Distal

DB: Distobuccal

DP: Distopalatal

P: Palatal

B: Buccal

Sample	Landmarks	CC 1	CC2	CC3
LB6	#26 M	0	0	0
	#25B	0	0	0
	#24P	0	0	0
RB6	#16MB	0	0	0
	#15P	0	0	0
	#17M	0	0	0
LB7	#26DP	0	0	0
	#24P	0	0	0
	#25D	0	0	0
RB7	#15B	0	0	0
	#16DB	0	0	0
	#14P	+	+	0
LB8	#27MB	0	0	0
	#25D	0	0	0
	#25B	0	0	0
RB8	#17MB	0	0	0
	#16M	0	0	0
	#15B	0	0	0
LB9	#27DP	0	0	0
	#25B	0	0	0
	#24B	0	0	0
RB9	#16MB	0	0	0
	#15B	0	0	0
	#14B	0	0	0
LB10	#27DP	0	0	0
	#26DP	0	0	0
	#26MB	0	0	0
RB10	#16DB	0	0	0
	#16D	0	0	0
	#17Centre	0	0	0

Table 3 Accuracy analysis of the first virtual inter-occlusal record

Reading 1			
	Sites of Close Proximity (Contacts)	**Sites of Clearance (No Contacts)**	
Present	52	3	Positive Predictive Value = 95%
Absent	8	57	Negative Predictive Value = 88%
	Sensitivity = 87%	Specificity = 95%	

Table 4 Accuracy analysis of the second virtual inter-occlusal record

Reading 2			
	Sites of Close Proximity (Contacts)	**Sites of Clearance (No Contacts)**	
Present	49	2	Positive Predictive Value = 96%
Absent	11	58	Negative Predictive Value = 84%
	Sensitivity = 82%	Specificity = 97%	

Table 5 Accuracy analysis of the third virtual inter-occlusal record

Reading 3			
	Sites of Close Proximity (Contacts)	**Sites of Clearance (No Contacts)**	
Present	51	4	Positive Predictive Value = 93%
Absent	9	56	Negative Predictive Value = 86%
	Sensitivity = 85%	Specificity = 93%	

Table 6 Reproducibility analysis of sites of close proximity

Sites of close proximity	
Scenario 1 (+++)	44
Scenario 2 (000)	4
Scenario 3 (++0)	8
Scenario 4 (00+)	4
Total	**60**

Table 7 Reproducibility analysis of sites of clearance

Sites of Clearance	
Scenario 1 (000)	55
Scenario 2 (+++)	1
Scenario 3 (00+)	2
Scenario 4 (++0)	2
Total	**60**

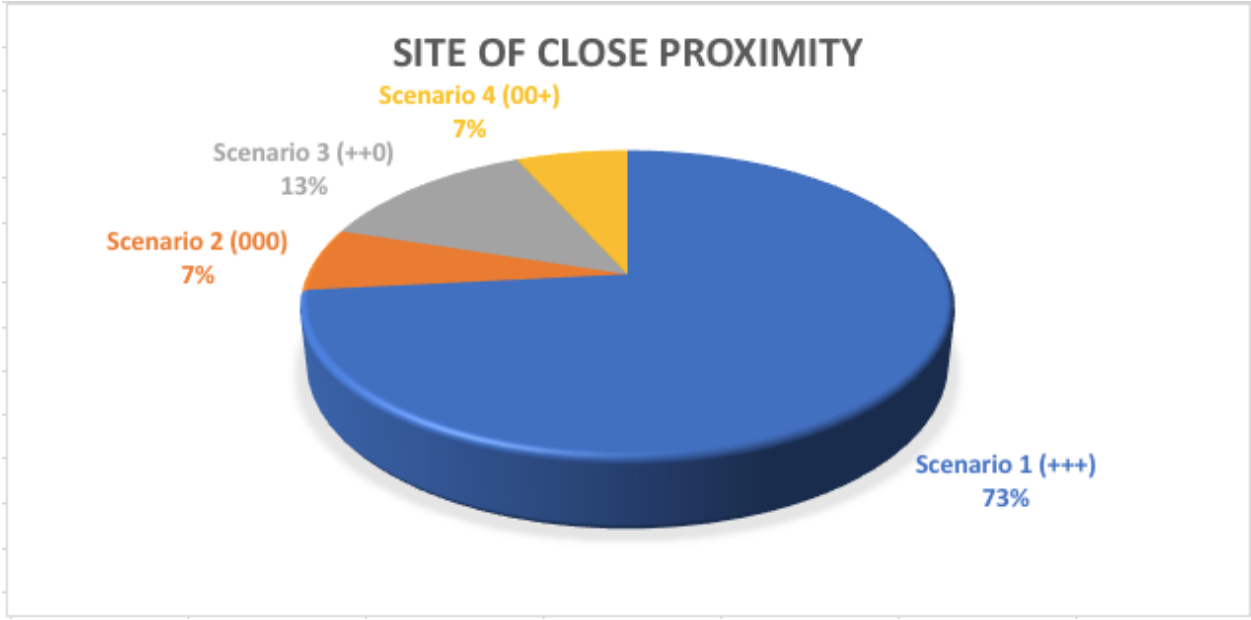


Figure 28 Analysis of reproducibility of sites of close proximity

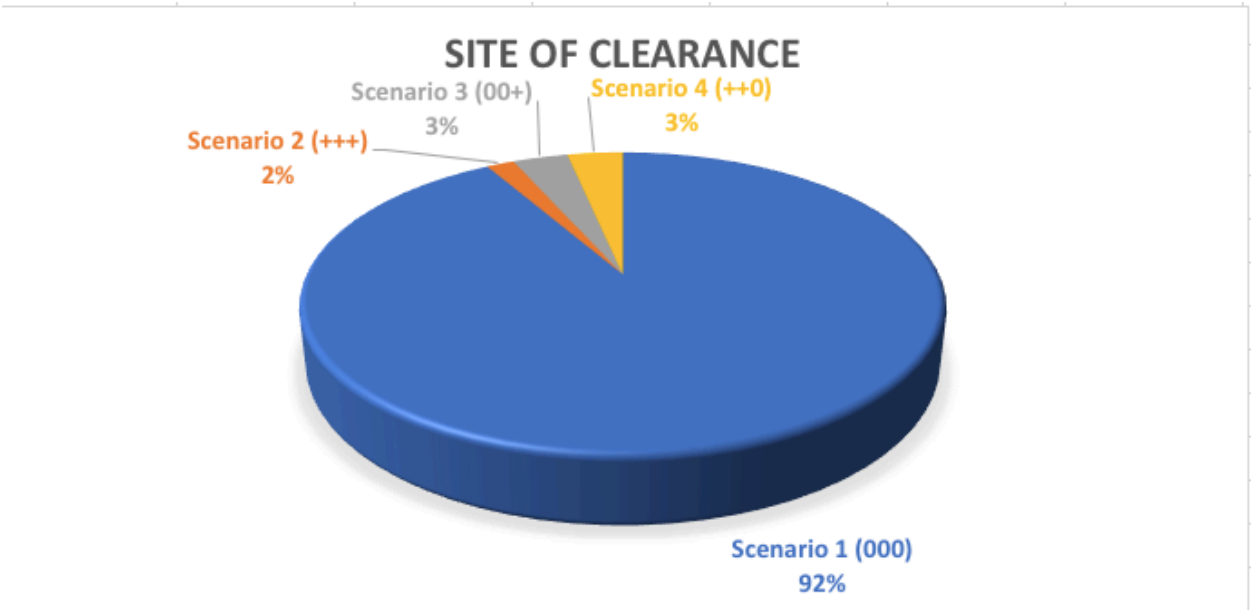


Figure 29 Analysis of reproducibility of sites of clearance

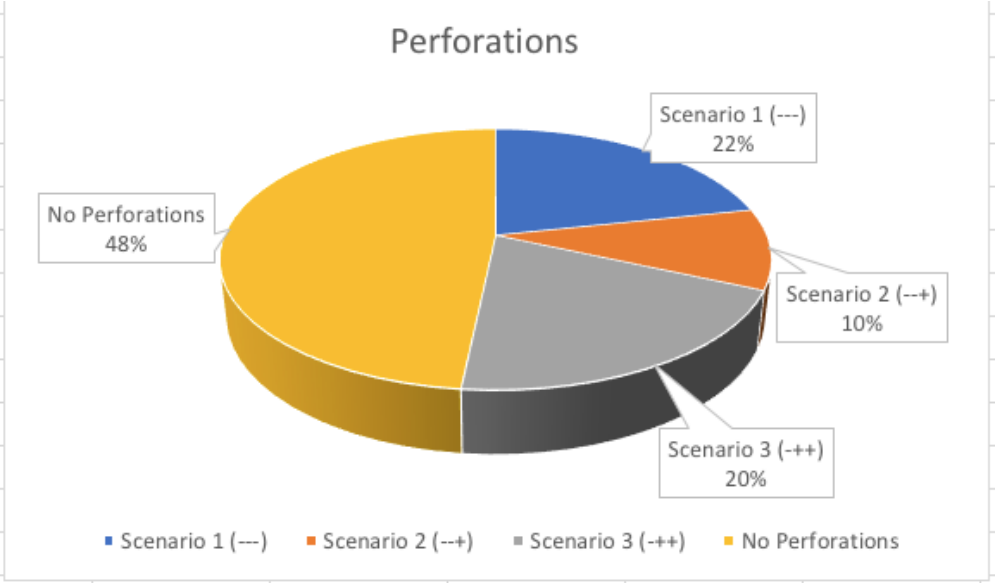


Figure 30 Frequency of inter-occlusal perforations with sites of close proximity analysis

Chapter 3: Discussion

Accurately examining the occlusion and obtaining inter-occlusal records is fundamental to successful prosthetic dentistry. Dental casts mounted on mechanical articulators, using an inter-occlusal record are then transferred to the lab technician for the construction of prostheses. With improvements in digital dentistry, intra-oral scanners allow for fabrication and articulation of virtual casts. The precision of intra-oral scanners is comparable to that of conventional impressions techniques when obtaining quadrant scans[55], however additional verifications is needed when it comes to the virtual inter-occlusal record. [77].

This study attempted to evaluate the virtual inter-occlusal records used to mount the digital casts. Only a few researchers have investigated the accuracy of virtual inter-occlusal records. [9, 67, 69] Generally, the studies that have evaluated virtual inter-occlusal records obtained by using intra-oral scanners and concluded that this process is accurate, however, these studies were all performed in-vitro and most of them used extra-oral scanners. [68, 70, 71]

The use of trans-illuminated PVS inter-occlusal records has been proven to be superior to other conventional methods and could be considered as the gold standards for these types of studies.[7, 10, 73] Inter-occlusal contacts and sites of close proximity (SCP) have been described by several researchers as thickness of the trans-illuminated silicone inter-occlusal record material ranging from less than 30µm to as much as 350µm.[67] In this study, SCP were identified on the trans-illuminated inter-occlusal record as material thickness being ≤100 µm. The use of 100 µm has been clinically identified as the cutoff that can have significant effects on inter-occlusal

relationship of the two arches yet it won't be influenced by the compressibility of the two opposing teeth when they come in contact.

Intraoral scanning using video acquisition technique usually works by stitching of the acquired sequential images to produce the final three dimensional model, which can introduce additional errors that could influence the articulation accuracy of the virtual cast.[57] Straga [78] stated that more overlapping scanning and digitization of dental casts results in less accurate the inter-occlusal records. To reduce the possibility of these errors, a single maxillary and mandibular quadrant scan was taken for each side of a participant, in this study.

The CEREC system shows a color-coded occlusal contact map of the occlusal contacts. One of the drawbacks of the system is the similarity between the shades of the color map of the distances between the opposing teeth, which in reality makes their interpretation harder. Also, knowing the error possibility of the best-fit operation or algorithm used in the software is essential in order to consider the possible errors in the results.[68] The algorithm used for calculating distances with CloudCompare is well known, unlike CEREC. In addition, CloudCompare has the advantage of setting the cutoff for the exact distance between the maxillary and mandibular casts to identify sites of close proximity.

In this study, accuracy of the digitally determined occlusal contacts was evaluated by sensitivity, specificity, positive and negative predictive values. The sensitivity for the three scans was 87%, 82%, and 85%, with the first scan having the highest percentage. However, reproducibility testing of the system in identifying sites of close proximity stated that only 73% of the contact areas were detected in all three scans, and 13% were detected in two out of three scans. This

implies that the CEREC system is missing some existing contacts, which might result in restorations fabricated with occlusal errors. The CEREC Omnicam scanning system shows good specificity in all three scans taken with percentages of 93%, 95% and 97%. The results of both specificity and reproducibility tests indicate that the system is not introducing false positive contacts at sites of clearance. In agreement with those findings, positive predictive values for the scanning systems have been consistently high with 96% in two scans and 93% in the last one. Whenever the system marks an area as a contact, there is a high chance that it is a true inter-occlusal contact. On the other hand, negative predictive values lie between 84% and 88%, which indicates that when the software identifies an area as a site of clearance, there is still a slight chance that it's a missed true contact.

Clinical requirement for sensitivity and specificity for the digital inter-occlusal contacts have been recommended to be 70% for sensitivity and 95% for specificity. [10, 79] In this study, both tests have been conducted on the three digital inter-occlusal records and it indicated that the virtual inter-occlusal record is clinically acceptable according to the proposed criteria. However, specificity for the last digital inter-occlusal record was only 93%.

The SCP analysis of the virtual casts identified perforations or interpenetrations through the mesh of the opposing arch. Inter-occlusal perforations are a phenomenon that is not possible to be present on conventional casts or between natural teeth in the mouth. It's a feature that has been integrated in the system's software to aid in virtually aligning the maxillary and mandibular virtual casts into occlusion. Consequently, their presence might influence the accuracy of the inter-occlusal record as they are physically nonexistent.

Inter-occlusal perforations were also identified by Edher et al.,[72] where they found more of them with full arch scans as compared to quadrant scans. As a consequence, they recommended taking quadrant scans or articulating full arch scans with multiple bite scans if the software allows. This was also recommended by other studies, as well as acquiring multiple buccal bite scans, as far apart as possible. [69] [68] Based on those finding, only quadrant scans with buccal bite scan of the same side were utilized in the current study. Nevertheless, perforations were still generated by the CEREC software.

It is essential to consider the clinical significance of incorporating inter-occlusal perforations in the digital models and its influence on the final restorations. Since there are no real perforations intraorally and they only exist in the virtual models, a prosthesis fabricated based on the virtual articulations with perforations would be out of occlusion or have light contacts when placed in the mouth. In fact, with the increased use of CAD/CAM technology, it's been a common finding to receive restorations with no or light contacts with the opposing arch, which could be explained by the presence of inter-occlusal perforations. Although it might be beneficial to the clinicians to have prostheses in light or no occlusal contacts as it reduces the required chair-side time for occlusal adjustments, it doesn't represent the objective of prosthetic dentistry to maintain the existing occlusion. Restorations are usually fabricated to restore function and maintain occlusal stability of both jaws. This concern could be addressed by incorporating collision resolution to the software algorithms which aids in simulation of natural dental collision occurring intraorally. [67]

On the other hand, perforations could be compensation by the software for the periodontal ligament compressibility of the two opposing teeth in MIP. It is worth mentioning that those

perforations were observed more with certain participants than with others. It could be related to the way those participants brought their jaw together in maximum intercuspal position, their biting force and the compressibility of the periodontal ligament, and tooth mobility.

Limitations of the current study include the variability associated with clinical studies, which makes it hard to standardize as dental occlusion and jaw movements differ from one person to another. Although several factors have been controlled while taking the inter-occlusal records, such as patient's head tilt and the same verbal instructions to bite their teeth together, biting force likely varied greatly within and between participants Some teeth might have been compressed more than the others, which might have caused displacement of their position in relation to the opposing arch, which could affect the inter-occlusal record.

Trans-illumination has been used in several similar studies to digitize the conventional inter-occlusal records, however, it might introduce errors due to material thickness and angulation of the light passing through the PVS material.

Another limitation of the current study is that only one investigator was involved in identification of the sites of close proximity and sites of clearance. It would be beneficial if the data is analyzed with two independent investigators to investigate the variability between clinicians with respect to the interpretation of occlusal contacts and clearances. Finally, the study investigated static occlusal relationships with no simulation of excursive movements. Further research regarding virtual articulators and inter- occlusal records in protrusive and laterotrusive positions is advised.

Chapter 4: Conclusion

Based on the sensitivity and specificity testing of the virtual inter-occlusal record, accuracy of CEREC Omnicam intraoral scanning system in identifying inter-occlusal contacts is clinically acceptable. The tested intraoral scanning system has a tendency toward missing inter-occlusal contacts rather than introducing false contacts. Repeated buccal bite scans taken for the same side showed fair reproducibility, however, this area needs to be further investigated with more attempts to control the variability involved with clinical studies and the possibility of different biting forces every time a buccal bite scan is repeated.

Intraoral digital scans for virtual inter-occlusal records can be used clinically to virtually articulate casts. However, clinicians should be aware of phenomenon of inter-occlusal perforations incorporated into the CEREC software and its clinical consequences on the fabricated restorations. Depending on the CAD/CAM software, the resulting dental prostheses may have light or no occlusal contacts. Moreover, repeating the buccal bite scans for any reason might not result in identical occlusal relationships of the maxillary and mandibular virtual casts.

Future researchers should consider studying the accuracy of virtual inter-occlusal records in other excursive jaw positions and potentially simulate the mandibular dynamics. The accuracy of virtual inter-occlusal records taken under different bite force also needs to be evaluated.

References

1. *The Glossary of Prosthodontic Terms: Ninth Edition.* J Prosthet Dent, 2017. **117**(5S): p. e1-e105.
2. Ehrlich, J. and S. Taicher, *Intercuspal contacts of the natural dentition in centric occlusion.* J Prosthet Dent, 1981. **45**(4): p. 419-21.
3. DeLong, R., et al., *Accuracy of contacts calculated from 3D images of occlusal surfaces.* J Dent, 2007. **35**(6): p. 528-34.
4. Myers, G.E. and J.R. Anderson, Jr., *Nature of contacts in centric occlusion in 32 adults.* J Dent Res, 1971. **50**(1): p. 7-13.
5. Millstein, P. and A. Maya, *An evaluation of occlusal contact marking indicators. A descriptive quantitative method.* J Am Dent Assoc, 2001. **132**(9): p. 1280-6; quiz 1319.
6. Davies, S., et al., *Reliability of recording static and dynamic occlusal contact marks using transparent acetate sheet.* Journal of Prosthetic Dentistry, 2005. **94**(5): p. 458-61.
7. DeLong, R., et al., *Accuracy of contacts calculated from 3D images of occlusal surfaces.* Journal of Dentistry, 2007. **35**(6): p. 528-34.
8. Forrester, S.E., et al., *Occlusal measurement method can affect SEMG activity during occlusion.* J Oral Rehabil, 2011. **38**(9): p. 655-60.
9. Solaberrieta, E., et al., *Comparison of a conventional and virtual occlusal record.* J Prosthet Dent, 2015. **114**(1): p. 92-7.
10. Delong, R., et al., *Comparing maximum intercuspal contacts of virtual dental patients and mounted dental casts.* J Prosthet Dent, 2002. **88**(6): p. 622-30.
11. Millstein, P.L., *An evaluation of occlusal contact marking indicators: a descriptive, qualitative method.* Quintessence Int Dent Dig, 1983. **14**(8): p. 813-36.
12. Zuccari, A.G., et al., *Bulge ductility of several occlusal contact measuring paper-based and plastic-based sheets.* Biomed Mater Eng, 1997. **7**(4): p. 265-70.
13. Saad, M.N., et al., *Effects of load and indicator type upon occlusal contact markings.* J Biomed Mater Res B Appl Biomater, 2008. **85**(1): p. 18-22.
14. Saracoglu, A. and B. Ozpinar, *In vivo and in vitro evaluation of occlusal indicator sensitivity.* J Prosthet Dent, 2002. **88**(5): p. 522-6.
15. Schelb, E., D.A. Kaiser, and C.E. Brukl, *Thickness and marking characteristics of occlusal registration strips.* J Prosthet Dent, 1985. **54**(1): p. 122-6.
16. Kerstein, R.B., *Articulating paper mark misconceptions and computerized occlusal analysis technology.* Dental Implantology Update, 2008. **19**(6): p. 41-6.
17. Carey, J.P., et al., *Determining a relationship between applied occlusal load and articulating paper mark area.* The open dentistry journal, 2007. **1**: p. 1-7.
18. Kerstein, R.B. and J. Radke, *Clinician accuracy when subjectively interpreting articulating paper markings.* Cranio, 2014. **32**(1): p. 13-23.
19. Carossa, S., et al., *Evaluation of occlusal contacts in the dental laboratory: influence of strip thickness and operator experience.* Int J Prosthodont, 2000. **13**(3): p. 201-4.
20. Gazit, E., S. Fitzig, and M.A. Lieberman, *Reproducibility of occlusal marking techniques.* Journal of Prosthetic Dentistry, 1986. **55**(4): p. 505-9.
21. Halperin, G.C., A.R. Halperin, and B.K. Norling, *Thickness, strength, and plastic deformation of occlusal registration strips.* J Prosthet Dent, 1982. **48**(5): p. 575-8.

22. Siirilae, H.S. and P. Laine, *The Tactile Sensibility of the Parodontium to Slight Axial Loadings of the Teeth.* Acta Odontol Scand, 1963. **21**: p. 415-29.
23. Tryde, G., O. Frydenberg, and N. Brill, *An assessment of the tactile sensibility in human teeth. An evaluation of a quantitative method.* Acta Odontol Scand, 1962. **20**: p. 233-56.
24. Harper, K.A. and D.J. Setchell, *The use of shimstock to assess occlusal contacts: a laboratory study.* Int J Prosthodont, 2002. **15**(4): p. 347-52.
25. Maness, W.L., et al., *Computerized occlusal analysis: a new technology.* Quintessence Int, 1987. **18**(4): p. 287-92.
26. Gazit, E. and M.A. Lieberman, *Occlusal contacts following orthodontic treatment. Measured by a photocclusion technique.* Angle Orthod, 1985. **55**(4): p. 316-20.
27. Durbin, D.S. and C. Sadowsky, *Changes in tooth contacts following orthodontic treatment.* Am J Orthod Dentofacial Orthop, 1986. **90**(5): p. 375-82.
28. Razdolsky, Y., C. Sadowsky, and E.A. BeGole, *Occlusal contacts following orthodontic treatment: a follow-up study.* Angle Orthod, 1989. **59**(3): p. 181-5; discussion 186.
29. Sakaguchi, R.L., G.C. Anderson, and R. DeLong, *Digital imaging of occlusal contacts in the intercuspal position.* J Prosthodont, 1994. **3**(4): p. 193-7.
30. Owens, S., et al., *Masticatory performance and areas of occlusal contact and near contact in subjects with normal occlusion and malocclusion.* American Journal of Orthodontics & Dentofacial Orthopedics, 2002. **121**(6): p. 602-9.
31. Yamashita, S., Y. Igarashi, and M. Ai, *Tooth contacts at the mandibular retruded position, comparison of two different methods for bite registration.* Journal of Oral Rehabilitation, 2002. **29**(9): p. 823-6.
32. Olivieri, F., et al., *New method for analyzing complete denture occlusion using the center of force concept: a clinical report.* J Prosthet Dent, 1998. **80**(5): p. 519-23.
33. Davies, S.J., et al., *Inter- and intra-operator reliability of the recording of occlusal contacts using 'occlusal sketch' acetate technique.* Br Dent J, 2002. **193**(7): p. 397-400.
34. Machado, N.A., et al., *Identification of occlusal prematurity by clinical examination and cone-beam computed tomography.* Brazilian Dental Journal, 2013. **24**(1): p. 64-7.
35. Gurdsapsri, W., et al., *Influence of clenching level on intercuspal contact area in various regions of the dental arch.* J Oral Rehabil, 2000. **27**(3): p. 239-44.
36. McLean, L.F., H.S. Brenman, and M.G. Friedman, *Effects of changing body position on dental occlusion.* J Dent Res, 1973. **52**(5): p. 1041-5.
37. Coelho, M.F., et al., *Influence of dental chair backrest inclination on the registration of the mandibular position.* J Prosthet Dent, 2015. **114**(5): p. 693-5.
38. Berry, D.C. and B.P. Singh, *Daily variations in occlusal contacts.* J Prosthet Dent, 1983. **50**(3): p. 386-91.
39. Riise, C. and S.G. Ericsson, *A clinical study of the distribution of occlusal tooth contacts in the intercuspal position at light and hard pressure in adults.* J Oral Rehabil, 1983. **10**(6): p. 473-80.
40. Riise, C., *A clinical study of the number of occlusal tooth contacts in the intercuspal position at light and hard pressure in adults.* J Oral Rehabil, 1982. **9**(6): p. 469-77.
41. van der Zande, M.M., R.C. Gorter, and D. Wismeijer, *Dental practitioners and a digital future: an initial exploration of barriers and incentives to adopting digital technologies.* Br Dent J, 2013. **215**(11): p. E21.
42. Pieper, R., *Digital impressions--easier than ever.* Int J Comput Dent, 2009. **12**(1): p. 47-52.

43. Mörmann, W.H., *The evolution of the CEREC system.* The Journal of the American Dental Association, 2006. **137**(suppl 1): p. 7S-13S.
44. Syrek, A., et al., *Clinical evaluation of all-ceramic crowns fabricated from intraoral digital impressions based on the principle of active wavefront sampling.* J Dent, 2010. **38**(7): p. 553-9.
45. Seelbach, P., C. Brueckel, and B. Wöstmann, *Accuracy of digital and conventional impression techniques and workflow.* Clinical oral investigations, 2012: p. 1-6.
46. Galhano, G.Á.P., E.P. Pellizzer, and J.V.Q. Mazaro, *Optical Impression Systems for CAD-CAM Restorations.* Journal of Craniofacial Surgery, 2012. **23**(6): p. e575-e579.
47. Persson, A.S.K., et al., *Digitization of simulated clinical dental impressions: Virtual three-dimensional analysis of exactness.* Dental Materials, 2009. **25**(7): p. 929-936.
48. Luthardt, R., et al., *Design and production of dental prosthetic restorations: basic research on dental CAD/CAM technology.* Int J Comput Dent, 2002. **5**(2-3): p. 165-76.
49. Zimmermann, M., et al., *Intraoral scanning systems - a current overview.* International Journal of Computerized Dentistry, 2015. **18**(2): p. 101-29.
50. Rekow, E.D., *Dental CAD/CAM systems: a 20-year success story.* J Am Dent Assoc, 2006. **137 Suppl**: p. 5S-6S.
51. 3, C., *Operating instructions for the acquisition unit.* Soirona The Dental Company, Bensheim, Germany
, 2004.
52. Birnbaum NS, A.H., Stevens C, *3D digital scanners: a high-tech approach to more accurate dental impressions.* Inside Dent, 2009. **5**: p. 70-74.
53. Ting-Shu, S. and S. Jian, *Intraoral Digital Impression Technique: A Review.* J Prosthodont, 2015. **24**(4): p. 313-21.
54. Patel, N., *Integrating three-dimensional digital technologies for comprehensive implant dentistry.* J Am Dent Assoc, 2010. **141 Suppl 2**: p. 20S-4S.
55. Ender, A., et al., *In vivo precision of conventional and digital methods for obtaining quadrant dental impressions.* Clin Oral Investig, 2015.
56. Ender, A., T. Attin, and A. Mehl, *In vivo precision of conventional and digital methods of obtaining complete-arch dental impressions.* J Prosthet Dent, 2015.
57. Patzelt, S.B., et al., *Accuracy of full-arch scans using intraoral scanners.* Clin Oral Investig, 2014. **18**(6): p. 1687-94.
58. Kuhr, F., et al., *A new method for assessing the accuracy of full arch impressions in patients.* J Dent, 2016. **55**: p. 68-74.
59. Ng, J., D. Ruse, and C. Wyatt, *A comparison of the marginal fit of crowns fabricated with digital and conventional methods.* J Prosthet Dent, 2014. **112**(3): p. 555-60.
60. Zarauz, C., et al., *Clinical evaluation comparing the fit of all-ceramic crowns obtained from silicone and digital intraoral impressions.* Clin Oral Investig, 2015.
61. Steinmassl, P.A., et al., *Evaluation of Currently Available CAD/CAM Denture Systems.* Int J Prosthodont, 2017. **30**(2): p. 116-122.
62. Joda, T. and U. Bragger, *Patient-centered outcomes comparing digital and conventional implant impression procedures: a randomized crossover trial.* Clin Oral Implants Res, 2015.
63. Schepke, U., et al., *Digital versus analog complete-arch impressions for single-unit premolar implant crowns: Operating time and patient preference.* J Prosthet Dent, 2015. **114**(3): p. 403-6 e1.

64. Gjelvold, B., et al., *Intraoral Digital Impression Technique Compared to Conventional Impression Technique. A Randomized Clinical Trial.* J Prosthodont, 2015.
65. Ando, K., et al., *Bite force measurement system using pressure-sensitive sheet and silicone impression material.* Dent Mater J, 2009. **28**(2): p. 212-8.
66. CloudCompare, *User Manual*. Version 2.6.1.
67. Stavness, I.K., et al., *Simulation of dental collisions and occlusal dynamics in the virtual environment.* J Oral Rehabil, 2016. **43**(4): p. 269-78.
68. Solaberrieta, E., et al., *Intraoral Digital Impressions for Virtual Occlusal Records: Section Quantity and Dimensions.* Biomed Res Int, 2016. **2016**: p. 7173824.
69. Solaberrieta, E., et al., *Determining the requirements, section quantity, and dimension of the virtual occlusal record.* J Prosthet Dent, 2016. **115**(1): p. 52-6.
70. Iwaki, Y., N. Wakabayashi, and Y. Igarashi, *Dimensional accuracy of optical bite registration in single and multiple unit restorations.* Operative Dentistry, 2013. **38**(3): p. 309-15.
71. Arslan, Y., et al., *Comparison of Maximum Intercuspal Contacts of Articulated Casts and Virtual Casts Requiring Posterior Fixed Partial Dentures.* J Prosthodont, 2016.
72. Edher, F., *Virtual interocclusal registration using intra-oral scanning*. 2017, University of British Columbia: Vancouver. p. 79.
73. Baba, K., Y. Tsukiyama, and G.T. Clark, *Reliability, validity, and utility of various occlusal measurement methods and techniques.* J Prosthet Dent, 2000. **83**(1): p. 83-9.
74. Owens, S., et al., *Masticatory performance and areas of occlusal contact and near contact in subjects with normal occlusion and malocclusion.* Am J Orthod Dentofacial Orthop, 2002. **121**(6): p. 602-9.
75. *Image J User Guide 1.46*.
76. DeLong, R., et al., *Accuracy of a system for creating 3D computer models of dental arches.* J Dent Res, 2003. **82**(6): p. 438-42.
77. Goracci, C., et al., *Accuracy, reliability, and efficiency of intraoral scanners for full-arch impressions: a systematic review of the clinical evidence.* Eur J Orthod, 2016. **38**(4): p. 422-8.
78. Straga, R.W., *Comparison of Occlusal Contacts on Mounted Dental Models to Contacts Identified on 3D Digital Models Using a New Virtual Alignment Method*. 2009: https://open.library.ubc.ca/cIRcle/collections/ubctheses/24/items/1.0067095, University of British Columbia, Vancouver, Canada.
79. Ogawa, T., T. Ogimoto, and K. Koyano, *Validity of the examination method of occlusal contact pattern relating to mandibular position.* J Dent, 2000. **28**(1): p. 23-9.

Appendices

Appendix A Consent Form

In-vivo comparison between digital and conventional inter-occlusal records

Principal Investigator: Chris Wyatt, BSc, DMD, MSc, Dip Pros
UBC/Dentistry
Oral Health Sciences

Co-Investigator(s): Saraa Abdulateef, MSc Graduate Student
UBC/Dentistry
Oral Health Sciences

1. Invitation

You are being invited to take part in this research study because you are a young adult who have no or few missing teeth and your current dentition allows for an accurate bite registration.

2. Your participation is voluntary

Your participation is voluntary. You have the right to refuse to participate in this study. If you decide to participate, you may still choose to withdraw from the study at any time without any negative consequences to the medical care, education, or other services to which you are entitled or are presently receiving.

This consent form describes the diagnostic procedures that are being carried out for research purposes. Please review the consent document carefully when deciding whether or not you wish to be part of the research and sign this consent only if you accept being a research participant. If you wish to participate in this study, you will be asked to sign this form.

Please take time to read the following information carefully and to discuss it with your family, friends, and doctor before you decide.

3. Who is conducting this study?

This study is being conducted by a graduate student as their MSc project under the supervision of the Principle Investigator (PI).

4. Background

The development of digital technology has changed many processes in practicing dentistry. It's been proved that working in a virtual setting improves quality of dental treatment and patient satisfaction. However, many of the digital dental procedures are still being defined by research such as the bite registration. Digital articulators are one of the digital technology aspects of dentistry that have recently improved significantly. Studies comparing digital and conventional bite registration approaches showed promising outcomes. However, clinical research is still lacking, and some digital systems do not provide virtual articulator software yet. Such clinical study evaluating the validity and reproducibility of the digital inter-occlusal records (bite registration) taken by an intra-oral scanner (an optic device used to scan the intraoral hard and soft tissues with no x-rays and ionizing radiation) would be a valuable addition to the dental literature. It would investigate the possibility of digitizing the whole dental procedure.

5. What is the purpose of the study?

The purpose of the current study is to validate the digital bite registration taken using an intra-oral scanner compared with the conventional technique using silicone material dispensed between the teeth by testing both methods clinically.

6. Who can participate in this study?

You may be able to participate in this study if:

- You are a young adult, aged between 20-40 years old.
- Dentate, minimum 24 teeth.

7. Who should not participate in this study?

You will not be eligible to participate in this study if:

- You have mobility in your teeth.
- You have a history of grinding.

8. What does the study involve?

If you agree to take part in this study, the procedures and visits you can expect will include the following: a quick examination is to be performed to determine if you have the minimum required teeth to be included in the study in addition to the absence of mobility. Then, you will be asked to bite in a certain position which is the maximum intercuspation (which is the position where the the teeth of one arch fully interpose themselves with the teeth of the opposing arch) for several times as a practice for the required position before we start to test the two methods.

Subsequently, the bite is first registered using the conventional technique by dispensing silicone material between your upper and lower teeth while you bite in maximum intercuspation. Next, an intraoral scanner is to be used to register the bite again by scanning both upper and lower arches separately as well as the bite at the same position. The required time for the whole process is estimated to be one hour.

9. What are my responsibilities?

- You will be required to attend one appointment only for approximately an hour.

10. What are the possible harms and discomforts?

The current study has no risk of any harms and discomforts.

11. What are the potential benefits of participating?

No one knows whether or not you will benefit from this study. There may or may not be direct benefits to you from taking part in this study. We hope that the information learned from this study can be used in the future to validate the use of digital interocclusal records in clinical practice.

12. What are the alternatives to participation?

Refuse to participate.

13. What if new information becomes available that may affect my decision to participate?

If you choose to enter this study and at a later date a more recent updates indicate that the proposed methodology is not recommended to be used to get an accurate interocclusal records, it will be discussed with you. You will also be advised of any new information that becomes available that may affect your willingness to remain in this study.

14. What happens if I decide to withdraw my consent to participate?

You may withdraw from this study at any time without giving reasons. If you choose to enter the study and then decide to withdraw at a later time, you have the right to request the withdrawal of your information collected during the study. This request will be respected to the extent possible. Please note however that there may be exceptions where the data will not be able to be withdrawn for example where the data is no longer identifiable (meaning it cannot be linked in any way back to your identity) or where the data has been merged with other data. If you would like to request the withdrawal of your data, please let your study doctor know.

15. Can I be asked to leave the study?

If you are not able to follow the requirements of the study or for any other reason, the study doctor may withdraw you from the study and will arrange for your care to continue. On receiving new information about the treatment, your research doctor might consider it to be in your best interests to withdraw you from the study without your consent if they judge that it

would be better for your health. If you are asked to leave the study, the reasons for this will be explained to you and you will have the opportunity to ask questions about this decision.

16. How will my taking part in this study be kept confidential?

Your confidentiality will be respected. However, research records and health or other source records identifying you may be inspected in the presence of the Investigator or his or her designate by Health Canada, and UBC Clinical Research Ethics Board for the purpose of monitoring the research. No information or records that disclose your identity will be published without your consent, nor will any information or records that disclose your identity be removed or released without your consent unless required by law.

You will be assigned a unique study number as a participant in this study. This number will not include any personal information that could identify you (e.g., it will not include your Personal Health Number, SIN, or your initials, etc.). Only this number will be used on any research-related information collected about you during the course of this study, so that your identity will be kept confidential. Information that contains your identity will remain only with the Principal Investigator and/or designate. The list that matches your name to the unique study number that is used on your research-related information will not be removed or released without your consent unless required by law.

Your rights to privacy are legally protected by federal and provincial laws that require safeguards to ensure that your privacy is respected. You also have the legal right of access to the information about you that has been provided to the sponsor and, if need be, an opportunity to

correct any errors in this information. Further details about these laws are available on request to your study doctor.

17. What happens if something goes wrong?

By signing this form, you do not give up any of your legal rights and you do not release the study doctor, participating institutions, or anyone else from their legal and professional duties. If you become ill or physically injured as a result of participation in this study, medical treatment will be provided at no additional cost to you. The costs of your medical treatment will be paid by your provincial medical plan and/or by the study sponsor.

18. What will the study cost me?

All research-related medical care and treatment and any related tests that you will receive during your participation in this study will be provided at no cost to you.

You will get a gift card which is worth 20 Canadian Dollars as a reimbursement for your time.

19. Who do I contact if I have questions about the study during my participation?

If you have any questions or desire further information about this study before or during participation, or if you experience any adverse effects, you can contact Saraa Abdulateef at 778-681-1990

20. Who do I contact if I have any questions or concerns about my rights as a participant?

If you have any concerns or complaints about your rights as a research participant and/or your experiences while participating in this study, contact the Research Participant Complaint Line in the University of British Columbia Office of Research Ethics by e-mail at RSIL@ors.ubc.ca or by phone at 604-822-8598 (Toll Free: 1-877-822-8598)

21. After the study is finished

Based on the results of the current study, the validity of using intraoral scanners to get the interocclusal records is to be determined in addition to providing recommendations about the most predictable way to use them clinically.

22. Signatures

In-vivo comparison between digital and conventional inter-occlusal records

Participant Consent

My signature on this consent form means:

- I have read and understood the information in this consent form.
- I have had enough time to think about the information provided.
- I have been able to ask for advice if needed.
- I have been able to ask questions and have had satisfactory responses to my questions.

- I understand that all of the information collected will be kept confidential and that the results will only be used for scientific purposes.
- I understand that my participation in this study is voluntary.
- I understand that I am completely free at any time to refuse to participate or to withdraw from this study at any time, and that this will not change the quality of care that I receive.
- I authorize access to my health records [insert if applicable and samples] as described in this consent form.
- I understand that I am not waiving any of my legal rights as a result of signing this consent form.
- I understand that there is no guarantee that this study will provide any benefits to me.

I will receive a signed copy of this consent form for my own records.

I consent to participate in this study.

_____

Participant's Signature Printed name Date

_____

Signature of Person Obtaining Consent Printed name Study Role Date