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A Digitized Comparison using Cone Beam Computed Tomography and Intraoral Scanning

Yvette Carrillo

LOMA LINDA UNIVERSITY
School of Dentistry
in conjunction with the
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A Digitized Comparison using Cone Beam Computed Tomography and Intraoral Scanning

by

Yvette Carrillo

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the requirements for the degree
Master of Science in Periodontics

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Each person whose signature appears below certifies that this thesis in his/her opinion is adequate, in scope and quality, as a thesis for the degree of Master of Science.

____, Chairperson
Erik Sahl, Associate Professor of Periodontics

____
Kenneth Abramovitch, Professor of Radiology and Imaging Sciences

____
Yoon Jeong Kim, Associate Professor of Periodontics

____
Heidi Kohltfarber, Associate Professor of Radiology and Imaging Sciences

____
Dwight Rice, Associate Professor of Radiology and Imaging Sciences, and Associate Professor of Dental Research

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ABBREVIATIONS

3D	3-Dimensional
CBCT	Cone Beam Computed Tomography
IOS	Intraoral Scanner
STL	Stereolithography
PEEK	polyether ether ketone
ICC	Inter Class Correlation
WSR	Wilcoxon Signed Rank Test
CAD-CAM	Computer aided design and computer aided manufacturing
STD	Standard Deviation
mm	Millimeters

ABSTRACT OF THE THESIS

A Digitized Comparison using Cone Beam Computed Tomography
and Intraoral Scanning

by

Yvette Carrillo

Master of Science, Graduate Program in Advanced Periodontics
Loma Linda University, June 2018
Dr. Erik Sahl, Chairperson

Purpose: The purpose of this study was to evaluate the accuracy of digital workflow by evaluating the absolute technical differences in various scanning methods on jaw models with scanning bodies.

Material and Methods: Twenty identical 3-dimensionally printed mandibular quadrant jaw models with a single implant and scanning body replacing a missing tooth in area #19 were examined. Cone beam computed tomography .STL files were used as the first test group. Intraoral scans were used as the second test group. Desktop scans of each model and the .STL file was used as a control. The .STL files were then superimposed onto each other using imaging software. Absolute differences were measured by manually selecting the same seven points in each model, and a best fit model was generated using 20,000 points of measurement. The average distance and standard deviation for each superimposition was generated by the software, and statistic evaluation was then conducted.

Results: The results revealed a statistically significant difference between both test groups and the control. A mean difference of .10 mm with a standard deviation of .044 for the CBCT scanned image files, and .05 mm with a standard deviation of .011 for the IOS scanned image files. Under the clinical significant value of .5 mm, both groups were significantly less than 0.5mm with $p<0.05$. Interclass correlation showed excellent reliability of overall superimposition (ICC=0.84, $p<0.05$)

Conclusion: The results show that the CBCT and IOS test group scanned files were statistically significantly different from the control desktop scans. Clinically, the differences may not be detectable.

CHAPTER ONE

INTRODUCTION AND REVIEW OF THE LITERATURE

Digital workflow in dentistry is becoming increasingly popular, and the forefront of dentistry. Cone beam computed tomography (CBCT) allows dentists to diagnose, build treatment options, and plan restorations by three dimensionally (3D) brining hard tissues to life that were otherwise available to dentist by only using panoramic and periapical radiographs. In addition, various optical scanning methods are commercially available and allow for interdisciplinary communication, collaboration, as well as provide patient education tools. Computer aided design and computer aided manufacturing, i.e., CAD-CAM completely changed the workflow in dentistry. Manufacturing, milling, and 3D printing of digitally planned treatment and materials allow the clinician to transfer digital information and provide an accurate and rapid service to the patient. Advancement of digital technology aids clinicians to make implant placement predictable, less time consuming, and in more ideal locations for the final restorative prosthesis[1-3].

In conventional dentistry, dental impressions are used to replicate the human dentition by pouring stone models out of the mold. Due to operator error in mishandling materials and improper use of the materials, errors can be made while taking impressions, and pouring stone models[4, 5]. Additionally, the inherent properties of dental materials cause distortion. The net result is inaccurate readings, which ultimately leads to increased chair time and inaccurate prostheses[6]. One of the goals of digital dentistry is to avoid as many as these handling property errors as possible by eliminating partially, if not fully the use of dental materials.

CBCT, 3D printed surgical guides, and intraoral scanning software are all innovative tools helping dental clinicians achieve a predictable and precise final restoration or prosthesis. Computer guided surgery has many benefits including patient comfort, shorter surgery time and reduced post-operative healing[7]. Digitally pre-planning the location of the dental implant allows for a laboratory to fabricate provisional prosthesis, and at times a definitive final prosthesis prior to surgery. This may allow for improved patient function and prosthetic result[5, 8].

Optical scanning allows for the conversion and digitization of 3D objects into digital format. Optical scanning has the ability to capture both hard and soft tissues, dental models, and articulators. The scanners may use a dust or titanium oxide powder in order to create a matte surface in order to prevent reflection of the saliva and teeth when the scanner is using LED light in order to capture a 3D image[9]. Some scanners are compatible with milling units that allow for same day delivery of final prosthesis[10].

Intraoral scanners have been used in dentistry for over thirty years[10]. With advances in technology full color digital imaging was made possible. In a study, intraoral scanners were compared for accuracy using typodont model containing a maxillary molar prepared for an all ceramic crown that scanned with 6 different scanners by a single dentist for trueness and precision. The results showed all scanners were found to be accurate and clinically acceptable, but small differences were seen between the devices[10].

In terms of the technical principles, each scanner varies by how the image is captured. The 3D model is built by the scanner by combining different images made of the model from different angles. Multiple images can be merged and provide the acquisition of intra and extra oral images into combined, superimposed digital images.

Light rays may be reflected into a sensor, and an algorithm is used to calculate the distance from the projector to the sensor. Additionally, Laser beam scanning projects a beam onto the object via a splitter, and the focal filter allows for the lens to capture the object[9].

Desktop scanners used by laboratory personnel utilize cameras and LED or laser light to capture dental stone models or conventional impressions and turn them into digital images[9]. Still image acquisition using a red laser projected onto an object takes several photographs and stitches them together[9]. LED technology allows for a proprietary reflected focal spot confocal image capture[9.] The scan time can be rapid (15-50 seconds) and it allows for color texture scanning and multiple die scanning, articulator scanning, and bite registration. The future of digital dentistry has endless possibilities and research is still lacking in some areas.

Conventional implant impression techniques are often still debated. Non-splinted and splinted-impression copings with carious materials and abutments along with transferred information to master models allows for dimensional distortions[11] . The accuracy of digital impressions as compared to conventional impressions has been evaluated, and has digital impressions have been shown to be similar to the conventional technique[12-14]. Liming factors do exist however, for the conventional method such as gag reflex due to dental trays and plaster material[15, 16]

Implant scanning bodies allow for the implant- restorative collaboration by providing a marker and measuring tool for the clinician. Scan bodies are also known as precision scanners, scan posts, scan abutments, scan flags, or scan locators. The scan bodies allow the position and orientation of the dental implant in CAD-CAM scanning procedures, and thus allow for alignment of the subsequent restoration. Unfortunately, compatibility of the scan body with software, and scanning system is not completely universal[7]. Some scan bodies are screw retained and intended for single use, and some companies allow for sterilization for multiple use (a maximum use of 5-100 times). The error can occur during scanning if the scan bodies are fixed improperly or there are deformities, scratches, or warp of the scan bodies due to sterilization. The material of scan bodies varies as well, they may be made from polyether-ether-ketone material (PEEK) or titanium. Little to no information is available on scan body material properties and the impact on digital scanning.

The trueness of scanned data whether from optical scans or computed tomography scans, leads to question the reproducibility and compatibility of various software and scanning methods. Little information is available as far as the accuracy and precision of optical scanning using implant scan bodies. Investigating the accuracy and precision in complete digital workflow available in dentistry would be beneficial, and is needed to improve quality and patient experience[17-19].

In addition, there is little information about CBCT and STL file conversion. Fully digital workflow allows for hard tissue superimposition beneath gingival and tooth architecture. The influence on data collection, file conversion, and superimposition distortion that an open loop architectural system may have on final outcome has not been studies thoroughly[20, 21] .

AIM

The purpose of this study was to evaluate the accuracy of digital workflow by evaluating the absolute technical differences in various scanning methods on jaw models with scanning bodies.

The null hypothesis was that there was no difference between the scans taken by the intraoral scanner (IOS) and CBCT, when compared to the desktop scanned control.

CHAPTER TWO

MATERIALS AND METHODS

Jaw Models

Twenty mandibular quadrant jaw models of teeth #18-#26 were printed (StrataSysObject30 Orthodesk 3D printer, Eden Prairie, MN) from the scan of one subject with a single edentulous space in the region of #19. Each model received a dental implant (4.3 mm x 8.0 mm Nobel Biocare Tapered Replace Select; Yorba Linda, CA) in #19 area with computer tomagraphy aided surgical guides[1]. A scanning body was hand torqued onto the implant using a hand screw driver until they were secure in each twenty printed jaw models. A PEEK material was chosen due to it's non-reflective properties. The models were then digitized by various methods.

CBCT Scans

All twenty models with the attached scanning body were scanned individually using a CBCT scanner (NewtomVGI, Biolase; Irvine, CA) by a skilled technician*. CBCT was taken with a field view of 6X6 cm, 75µm resolution. The exposure settings were 110kvp and at 0.55mA and 5.4 seconds with a 2.99mAs. The CBCT image files were saved as DICOM files, then converted to a .STL files using planning software (InVivoDental 5.4 software Anatomage, San Jose, CA). The .STL data from the CBCTs was used as the first test group.

Optical Scans

The models with the scanning bodies were placed on a benchtop with a blue background. Each model was scanned by a single examiner using a commercially available intraoral scanner (Trios 3Shape, 3D Systems, Houston Texas). The optical scanner was set at single restoration in the mandible, and the scan was taken using a previous method as described by Muller[22]. Briefly, the wand was slowly guided along the occlusal plane, not touching the model, followed by the lingual area, and finally the buccal, slowly rolling motions. When the scanner had completely pieced together the image, the scanned IOS .STL data was used as the second test group.

A desktop scanner (3Shape D900L Desktop Scanner, 3D Solutions, Houston, Texas) was used to take optical images and comprised control group. The 20 models with the scanning bodies were placed inside the desktop scanner and images were taken by a skilled laboratory technician[Φ].

Superimposition

The .STL CBCT files and .STL optical scan data files of the same model were then merged using a commercially available engineering software (Geomagic, 3D Systems Cary, NC) (Figure 1). Seven different points of the scanning body were used to manually superimpose the test group with its corresponding control group. The software then created a best fit model of the merged data (Figure 1). The absolute technical differences and standard deviation(SD) to the nearest milimeter (mm) was automatically generated in delta value by the software. After a wash-out period of two weeks, three random models were chosen and the measurements were repeated for reproducibility and accuracy of each scanning method. Color maps of the CBCT and IOS test group show the volumetric differences to the nearest µm of the scanned quadrant model to its corresponding control (figure 1).

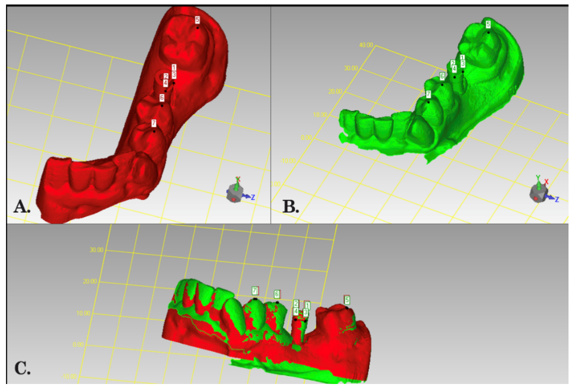

Figure 1. A. Superimposition of the CBCT scaned file (red) with the B. Desktop control (green) showing the seven points selected in each model to allow for superimposition. C is showing the best fit model

Statistical Analysis

ISPSS software (SPSS statistics 24.0, SPSS Inc., Chicago, IL, USA) was used to perform a statistical analysis. Descriptive statistics were reported as the mean and standard deviation. One Sample t-test was used to find the difference between two test groups and control group after superimposition. Paired t-test was used to compare the differences in superimposition between IOS and CBCT test groups. The reliability of superimposition was tested after repeating the process in 10 samples in each group for a total of twenty superimpositions after two months waiting period. Interclass correlation for absolute agreement was used to assess the reliability. Under the clinical significant

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∗Karen Lane RDA
ΦMalcolm Paul Richardson CDT

value of .5 mm, both groups were evaluated for clinical significant differences using a paired t-test to compare the clinical differences in superimposition between IOS and CBCT test groups.

CHAPTER THREE

RESULTS

Twenty IOS and twenty CBCT superimpositions were made so a total of forty superimpositions were evaluated for average deviation distance in mm between two images. A mean ± SD difference between IOS test group and control was 0.057 mm ±0.013 and mean difference of 0.107 mm ±045 mm for the CBCT test group (table 1). Figure 2 shows the boxplots for the IOS and CBCT test groups and mean differences, standard deviation, and the range as seen in mm.

Table 1. Mean, minimum and maximum differences between test groups when compared to the desktop and total differences of both test groups

Group	Mean (SD) mm	Minimum (mm)	Maximum (mm)
IOS	0.056 (0.012)	0.041	0.088
CBCT	0.107 (0.044)	0.016	0.192
Total	0.082 (0.041)	0.016	0.192

Differences Between Test Groups compared to Control

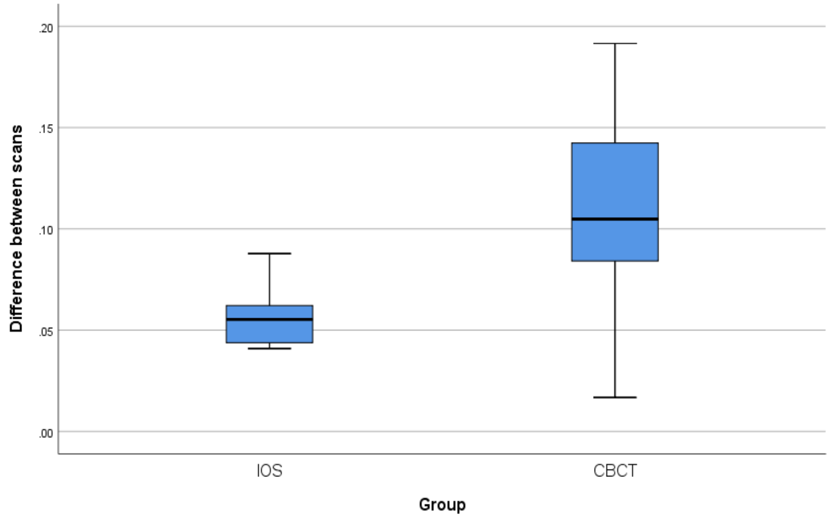

Figure 2. is a box plot showing the differences between test groups and the controls. The dark line between the box demonstrates the mean, the whiskers demonstrate the upper and lower limits.

A single sample t-test showed statistically significant difference existed between IOS and control (t=22.43 p< .001), and CBCT and control (t=10.63 p< .001, table 2)

Table 2. One-Sample test showing the differences between the test group scans, t- value, p value, mean difference, and confidence interval.

Test Value=0						
					95% Confidence Interval of the Difference	
Group	t	df	Sig (2-tailed)	Mean Difference	Lower	Upper
CBCT	10.633	19	.000	.1070612000	.08598655	.12813585
IOS	22.431	19	.000	.057167825	.05183360	.06250205

A paired-sample t-test was conducted to compare the average deviation of IOS and CBCT. There was a significant difference between both groups with mean difference of 0.049 ±0.046 mm (t= -4.839 p<.001, table 3).

Table 3. Paired sample statistics showing the mean difference, standerd deviation and standard error between the test gorups and the control.

	Mean	Std Deviation	Std Error Mean	Lower	Upper	t	df	Sig(2-tailed)
Pair 1 Change between IOS and Desktop-Change between CBCT and Desktop	-.04989	.046s106724	.010309777	-.07147198	-.02831476	-4.83	19	.000

Reliability of each superimposition on the engineering software system was evaluated using in Intraclass Correlation (ICC) 50% of the samples. ICC for the CBCT superimposition was 0.762 p=0.022 on the 20 scans, ICC for the IOS superimposition was 0.872 , P=.003

CHAPTER FOUR

DISCUSSION

The results of this in vitro study show that the CBCT and IOS were statistically significantly different from the desktop controlled scans. The null hypothesis was rejected by both the CBCT and IOS group when compared to the desktop control.

To the authors knowledge, this is the first study comparing CBCT and IOS digitized models compared to a desktop control digitized model. The IOS test group had a mean difference of .056 ± 0 .012 with the minimum difference being .042 mm and the maximum difference of 0.088 mm. The IOS test group had a narrow range of differences between scans. The CBCT test group had a mean difference of 0.017 ± 0.044 mm with a minimum of 0.16 mm and maximum difference of 0.192 mm. Though the CBCT group had a wide range, one sample of CBCT scan showed the smallest deviation, 0.016 to its corresponding. The most inaccurate superimposition was also seen in the CBCT test group.

The results of this study agree with previously published data [2, 5]. In this study, the IOS group displayed a narrow dispersion of difference, showing the precision of the IOS. In a previous study, the precision of the IOS was greater than that of six other intra oral scanners[2]. The IOS scanner has the capability to capture color, and texture as well as digitize the 3D image. The imaging software used in this study to calculate absolute differences, allows for reverse engineering as well as detecting color and texture between scanned images.

Figure 2 shows the boxplots for the IOS and CBCT groups and differences between scans as seen in millimeters. The IOS group shows a narrow band of distribution with narrow upper and lower limits, while the CBCT shows a wide band of distribution, and wide upper and lower limits. This graft indicates that though both means are well below .5 mm, the IOS images when compared to the control are more accurate and perhaps more reproducible when compared to the control. The CBCT group, while also well below .5 mm of clinical significance, had less predictability.

Color maps allow the viewer to assign a numerical value to a continuum of colors, in this study a traditional rainbow color map was used[23]. The engineering software used in this study has been used in previous intraoral scanning studies[18, 24-26] . A best fit algorithm allows for analysis of distance and deviation between superimpositions. The color map between the CBCT and IOS as seen in figures 4 and 5 are mostly green indicating area of agreement. The areas of disagreement are displayed in red. A legend on the right shows the maximum and minimum critical value of -2.0 mm and 2.0 mm, differences between the two surfaces is given in absolute average distance.

A possible explanation for the differences in both test groups when compared to the control, is that the software used for measurement detects texture and color as scatter. The jaw models that were used were 3D printed, and so a possible explanation is the accuracy of the IOS allowed for the texture in the model to be picked up by both the IOS and desktop scanner which utilize an LED light[9]. The CBCT digitized models, on the other hand were in DICOM format and converted to .STL files and so the translucency of the printed model could have added slight scatter on the digitized format due to the previously placed implants.

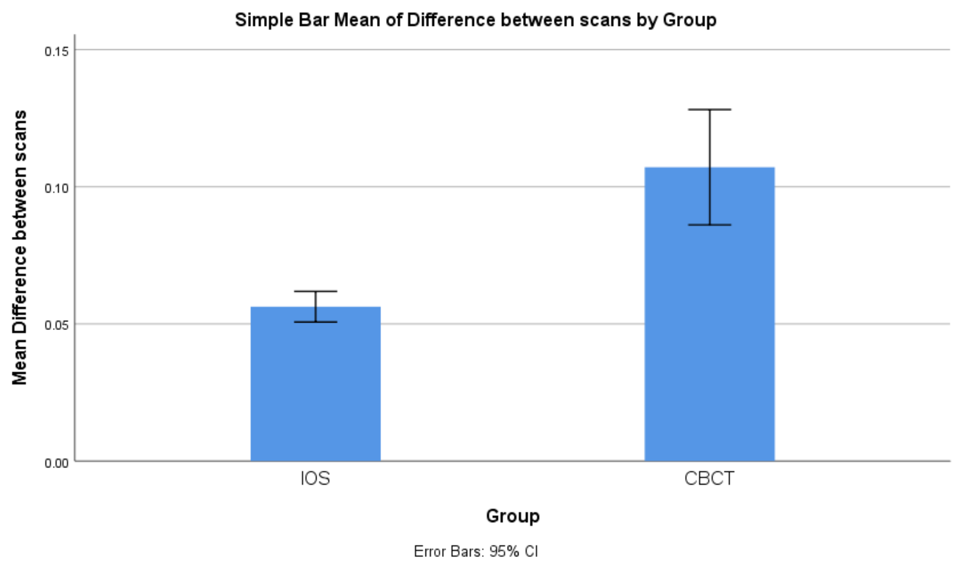

Figure 3. Bar graphs showing the mean differences between the IOS and CBCT.

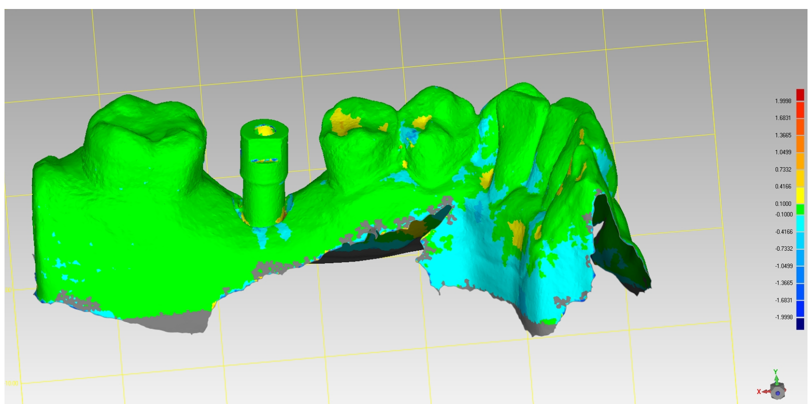

Figure 4. Color map of absolute differences of CBCT scanned images.

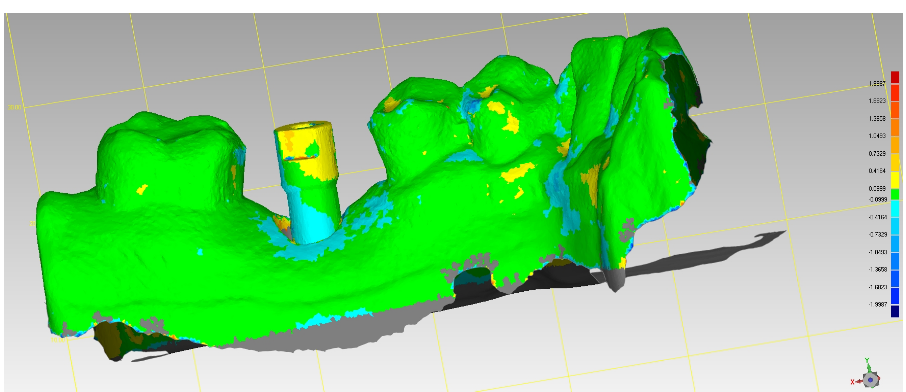

Figure 5. Color map of absolute differences of IOS scanned images.

Figure 3 shows the mean differences between the scans in millimeters. This figure illustrates that the CBCT is less predictable, and not as precise as the IOS superimpositions when compared to the control. The bar graph is used to show the superimposition between the test group and the controls, both groups are well below .15 mm and clinically, the difference between scans when compared to the desktop control is minimal and seen in millimeters, which may not be detectible at a clinical level. Though clinical significance is uncertain, a Clinical study of digital workflow reported no complications after fully digital planning of implant supported fixed restoration in fifteen patients at 6 months[20] . Similar results using this study model may be obtained should further be explored.

Table. 4. Interclass Correlation Coefficient for CBCT and IOS and total superimpositions.

Group	N	ICC	p-value
CBCT	20	0.76	0.02
IOS	20	0.87	0.001
CBCT+ IOS	40	0.84	0.001

Limitations of the study include a learning curves for the machinery, including the intra oral scanner, the software, and the CBCT. The IOS is a wireless hand held wand that takes video images of the teeth and soft tissues, or study models. Using the wand with one hand is difficult, in this study the model was placed benchtop and the intra oral scanner was rotated around the teeth as described by Muller[22]. Intra orally the cheeks, tongue, saliva, and patient movement make scanning more difficult[27]. Statistically, there was a difference seen between the IOS and the control desktop group. The texture differences would reflect the light differently because the IOS utilizes a LED light, the roughness of the 3D printed jaw models may have been detected by the sensor.

Last, this study was under a controlled setting and so limiting factors such as saliva, cheeks, and tongue were excluded. In addition, it would be beneficial to evaluate the technical differences between implant scanning body position when compared to a single control utilizing an intra oral scanner. [27] The light reflective properties of teeth, restorations, and saliva could cause distortion and gaps in the intraoral scan in the clinical setting.

Another possible limitation is that the CBCT files were in DICOM format and were converted to .STL files using digitizing software. The conversion itself may lead to minor distortion, however, if differences are at all detectible at all is uncertain. In a patient radiopaque images such as crowns, implants, and restorations can add to the noise and distortion to what is considered the final interpretation of the DICOM files, this may also lead to surface irregularities detectible through the analyzing software. [21]

When computing a global registration, the assumption is that the point reference chosen is the same each time. The software used to measure the scans can calculate differences of up to .000000 mm, for that reason, the error may appear large. For this study 20,000 points were used to evaluate the absolute average distance and standard deviation. All of the test groups had absolute differences significantly less than .5 mm when compared to the control, as seen in figure 3 so, the technical difference, may not be clinically detectable. Table 5 shows a one sample t test for clinical significance and the results show that both test groups are clinically significantly similar to the control.

Table 5. One sample statistics showing the mean difference, standerd deviation and standard error between the test gorups and the control when compared to 0.5 mm.

	Test Value=0.5			95% Confidence Interval of The Difference	
Group	t	Sig (2-tailed)	df	Lower	Upper
Change between CBCT and Dsktop	-39.117	.000	19	-.41390757	-.37186391
Change between IOS and Desktop	-166.061	.000	19	-.44932665	-.43814109

Digital impression techniques may be more time efficient, patient friendly, cause less breathing difficulty, TMJ pain as the mouth is not kept open as long, and so is preferred over the conventional technique[28]. The results of this study show the precision of the intraoral scanner, as well as the clinical significance both the IOS and CBCT in a digital workflow. Table 5, Figure 6

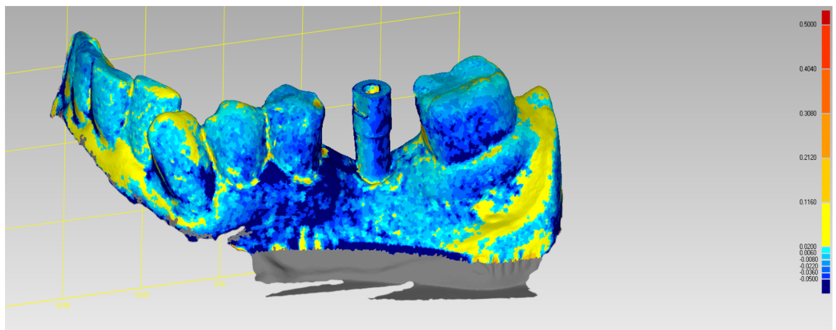

Figure 6. Color map of clinical differences in an IOS scanned images. The legend on the right shows a difference of (+/-)0.5 mm

CHAPTER FIVE

CONCLUSION

The results of this study are that the CBCT and IOS group reject the null hypothesis that there is no difference between scanning methods when compared to the Desktop scanned control. The IOS test group had a mean difference of .056 mm, while the CBCT test group had a mean difference of .107 mm. The IOS test group showed higher precision, the most accurate scan, however, was in the CBCT test group.

Clinical significance determined as .5 mm, and all scans were less than 0.5 mm. The results are likely not clinically significant, and more research utilizing a patient model is necessary.

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