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Comparison of intraoral and extraoral scanners on the accuracy of digital model articulation

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Abstract

Introduction: Orthodontists increasingly rely on digital models in clinical practice. The ability of modern scanners to articulate digital models must be scientifically evaluated.

Methods: Twenty five digital articulated models were produced from four digital scanners in five experimental groups. The resulting inter-arch measurements were compared to the gold standard. An acceptable range of 0.5mm more or less than the gold standard was used for evaluation.

Results: iTero® and iTero® Element yielded all acceptable inter-arch measurements. The 3M™ True Definition and Ortho Insight 3D® with Regisil® bite registration produced four of six acceptable inter-arch measurements. The Ortho Insight 3D® with Coprwax ™ bite registration yielded three of six acceptable inter-ach measurements.

Conclusions: The iTero® and iTero® Element produced the most accurately articulated models. The 3M™ True Definition and Ortho Insight 3D® with Regisil® were the next most accurate. The Ortho Insight 3D® scanner with Coprwax ™ was the least accurate method tested.

Introduction

Digital models have several advantages over conventional plaster models. They require less storage than the estimated $17m^3$ of storage required per one thousand patients that plaster models require.[1] Another advantage is the ease of accessibility and transferability of the models for consulting with other clinicians.[2] In addition, digital software systems have been shown to include many useful features that aid in model analysis such as linear measurements, arch perimeter analysis, and Bolton analysis.[3] Digital models have largely been reported to be accurate and to serve as a viable alternative to physical plaster models with regard to most intra-arch measurements.[2,4,5]

Recent developments in digital scanning have allowed the option of having in-house machines that can create orthodontic digital models. This technology has eliminated the additional step of sending impressions or models to an outside company to produce digital model files. Two readily available methods of obtaining digital models in-house include direct intraoral scanning and indirect extraoral scanning of plaster models. Three popular examples of intraoral scanners include the iTero® original scanner (Align Technology Inc., San Jose, CA), the iTero® Element (Align Technology Inc., San Jose, CA), and 3M™ True Definition scanner (3M ESPE, St Paul, MN). An example of the extraoral in-house scanner is the Ortho Insight 3D® laser surface scanner with Motion View Software (Motion View Software LLC, Chattanooga, TN).

The method for digital model articulation is different depending on the specific scanner used. The iTero®, iTero® Element, and 3M™ True Definition scanners replicate articulation from a direct scan of the teeth in occlusion. Alternatively, the extraoral Motion View scanner creates digital models in articulation by scanning maxillary and mandibular plaster casts with a physical bite registration. In addition, there are many other differences between these scanners including the need for powder use during scan with the 3M™ True Definition scanner, continuous scanning with the iTero® Element and 3M™ True Definition scanner, and the prerequisite of creating a plaster model for the Ortho Insight 3D® laser surface scanner.

There are several factors that are considered in the decision-making process when choosing a digital model scanning system. Cost, ease of use, office space, convenience, patient preference, and accuracy are important characteristics when determining the system of choice. One factor that has been previously evaluated is patient preference.[6,7] Grunheid, et al.[6] reported patients preferred alginate impressions to the intraoral scan because they found the conventional method "quicker" and "easier". On the other hand, Burhardt, et al.[7] concluded that patients preferred digital scanners due to increased comfort and decreased queasiness. Other studies have underscored the importance of accurate models and have reported that information gathered from study models was the most important component in treatment making decisions.[8,9] Another study comparing treatment plans made with the use of plaster versus digital models showed that there was a disagreement between the treatment options because of errors in the articulation of the digital models.[10] This highlights the importance of articulation accuracy in new digital model scanners.

The importance of correct articulation is also emphasized in the American Board of Orthodontics (ABO) scoring guidelines where points are given for discrepancies in inter-arch measurements such as occlusal contacts, overjet, and occlusal relationship. Molar classification, overbite, overjet, and canine classification all rely on correctly articulated models. Therefore, accuracy is not only important in the assessment of intra-arch measurements such as crowding and tooth-size discrepancy but also in the determination of intermaxillary relationship.

In general, both intraoral and extraoral scanners show accurate intra-arch measurements. Measurements obtained using digital intraoral scanners are reported to have near perfect agreement with those determined by actual clinical assessments.[4] Plaster models made from alginate impressions that are subsequently scanned into digital models have also been shown to have very accurate intra-arch measurements.[11] A recent systematic review by Rossini, et al.[5] on diagnostic accuracy and measurement sensitivity of digital models indicated that, in general,intra-arch measurements from digital casts are extremely accurate. However, the authors reported that inter-arch (articulation) related characteristics such as occlusal indices, occlusal contacts, and occlusal relationships exhibited significant differences.[5]

Most of the previous work on the accuracy of articulation investigated digital models produced by companies that specialize in digital modeling.[12-15] These studies reported that professionally made digital models rendered accurate inter-arch measurements such as overjet and overbite. On the other hand, in a previous investigation, in-house extraoral scanning from plaster to digital models was shown to produce inaccuracies in the inter-arch measurements due to articulating errors.[16] It was found that despite the use of the most accurate bite registration material, the occlusion resulted in significant errors in articulation.

Intraoral scanners are marketed as devices with the most accurate representation of inter-arch relationship. Unfortunately, there is little scientific evidence exploring the accuracy of model articulation produced by in-house digital model systems. As the popularity of in-house digital scanners increases, all aspects including articulation with these systems should be scientifically evaluated.   Therefore, the purpose of this study was to determine the accuracy of articulation of models produced in-house by one extraoral and three different intraoral scanners.

Materials and Methods

Initially, an alginate impression of a plastic typodont (005-000; American Orthodontics, Sheboygan, WI) was produced. Subsequently, maxillary and mandibular plaster models were made using Fujirock plaster (GC America, Alsip, IL) according to the manufacturer's instructions. On these casts, US No. 2 and No. 4 round burs were used to make two indentations on the buccal surface near the gingival margins of the maxillary and mandibular first molars, canines, and central incisors (Figure 1). Two points of varying sizes were initially made to ensure that a standardized measuring point would be captured by the different scanners. Since the indentations produced by the No. 2 round bur were successfully registered by all scanners, these points were used for all measurements because using smaller indentations reduced variability in point selection during measurements.

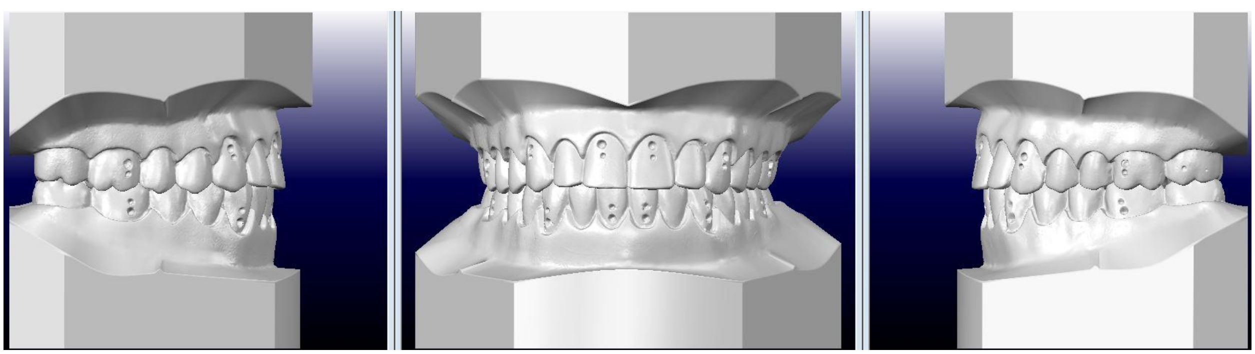

Figure 1 - Example of Indentations on Cast

The plaster model was then digitized using an Ortho Insight 3D® (OI3D) laser surface scanner (Motion View Software, Chattanooga, Tenn). The stone models were subsequently mounted in a semi-adjustable articulator (Whipmix, Louisville, KY) in the maximum intercuspal position (Figure 2). Digital calipers (Fowler High Precision USA, Newton, MA) were used to measure the distance between corresponding inter-arch markers. Six different inter-arch measurements were evaluated in this study. These measurements were as follows: Upper right 1st molar to the lower right 1st molar, upper right canine to the lower right canine, upper right central incisor to the lower right central incisor, and these same measurements on the left side. Each inter-arch measurement was repeated twenty five times, and the mean distance for each of the six different inter-arch measurements was used as the gold standard. This experimental set up was similar to the experiment performed in a previous study by Sweeney, et al. using the Ortho Insight 3D® scanner.[15]

Table 1 - Gold Standard Measurements with Defined Equivalence Bounds

	Average (mm)	**Lower Equivalence Bound (-0.5mm)**	**Upper Equivalence Bound (+0.5mm)**
Right Molar	5.2	4.7	5.7
Right Canine	10.5	10.0	11.0
Right Incisor	10.1	9.6	10.6
Left Molar	5.3	4.8	5.8
Left Canine	8.1	7.6	8.6
Left Incisor	9.5	9.0	10.0

Figure 2 - Model Articulation

One extraoral model scanner, Ortho Insight 3D laser surface scanner (Motion View Software, Chattanooga, Tenn), and three intraoral digital scanners were tested: iTero® 2.9

Scanner (Align Technology Inc., San Jose, CA), iTero® Element Scanner (Align Technology Inc., San Jose, CA), and 3M™ True Definition Scanner (3M ESPE, St Paul, MN). The iTero® 2.9 scanner will be referenced as iTero® Scanner throughout this paper. Twenty-five interocclusal records/scans of the experimental groups were made (Figure 3). The extraoral scanner experimental groups consisted of the Regisil® (Dentsply, York, PA) and Coprwax ™(Surgident- Heraeus, South Bend, IN) bite registration materials scanned with the Ortho Insight 3D laser surface scanner (Motion View Software, Chattanooga, Tenn).

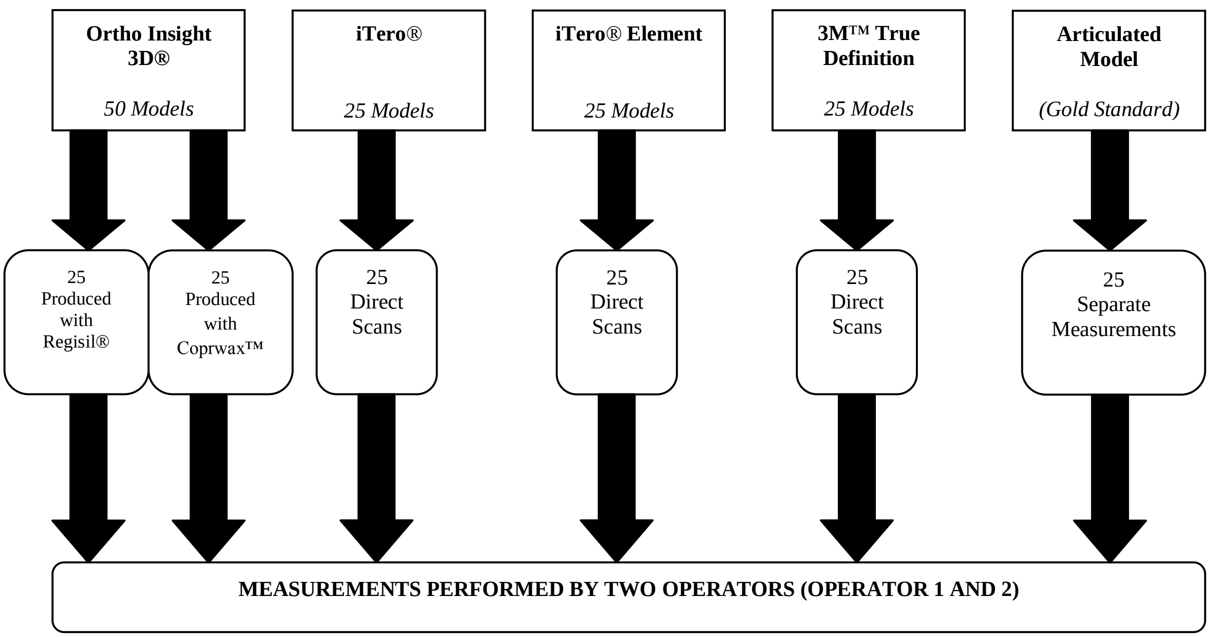

Figure 3- Groups Investigated – Each group of 25 was further divided into two subgroups (Subgroup 1:13 scans / Subgroup 2:12 scans). Operator 1 performed and recorded all measurements for subgroup 1 and operator 2 performed and recorded all measurements for subgroup 2

The extraoral scanner group protocol was similar to the protocol used in the study by Sweeney, et al.[16] For the extraoral scanner, two different articulations were generated using either Regisil® or Coprwax™. For the Regisil® group, vinyl polysiloxane (PVS) material was applied to the occlusal surfaces of the mandibular dentition, and the articulator was closed with manual pressure until the teeth were contacting in maximum intercuspation. A 1000-g weight was placed on top of the articulator to prevent expansion while setting. In the Coprwax™ group, the wax material was first heated in a water bath according to the manufacturer's instructions. It was then placed on the occlusal surfaces of the mandibular teeth. The articulator was closed until the teeth were contacting in maximum intercuspation. A 1000-g weight was placed on top of the articulator while the material cooled and hardened.

Each bite registration was scanned with the Ortho Insight 3D laser surface scanner within 10 minutes of setting. The digitized bite registrations were utilized to articulate the maxillary and mandibular digital models using the Motion View software to identify the teeth on both the bite registrations and the models. A best-fit surface-matching algorithm fit the maxillary model to the upper surface of the bite registration and the mandibular model to the lower surface. The occlusion resulting from this process was not modified by the investigators.

The intraoral scanner protocol followed the specific manufacturer's instructions and training for each scanner. During scanning of the bite, a 1000-g weight was placed on top of the articulator to maintain models in maximum intercuspation. The occlusion resulting from this process was not modified by the investigators.

Once all the digital models were produced in occlusion for all groups, the distance between corresponding inter-arch markers was measured using the applicable software for each scanner. Ortho Insight 3D software version 6.0.7044 (Motion View Software, Chattanooga, Tenn) was used to analyze models produced using the Ortho Insight 3D laser surface scanner. OrthoCAD™ version 5.4.0.403 (Align Technology San Jose, CA) was used to analyze models produced using the iTero® and iTero® Element scanners. To analyze models produced with the

3M True Definition scanner MeshLab version 1.3.4 (MeshLab Visual Computing Lab – Italian National Research Council – CNR) was used.

The differing scanner software platforms were compared to one another using one specific intra-arch measurement from the No. 2 bur indentation on the upper right 1st to the No.2 bur indentation on the upper right canine. This measurement was made on twenty five models produced by the 3M™ True Definition scanner, iTero® Element scanner, and Ortho Insight 3D laser surface scanner. These measurements were then compared to the gold standard.

All measurements were carried out by two operators who did not include the primary investigator. The operators were blinded to the purpose of the research study, and they were trained and calibrated prior to the start of the study. Operators were assessed for reliability within themselves and between each other. To evaluate the reproducibility and reliability, the digital models of twenty five randomly selected scans were re-measured one month later. Operators also measured identical twenty five digital models and were compared to each other to assess inter-rater reliability. Inter-rater and intra-rater reliability was assessed on the basis of standard deviation magnitude.

Statistical analysis

Experimental groups and software platforms were evaluated using two-one sided equivalence testing (TOST). The equivalence bounds were set to 0.5mm above and below the gold standard measurement. 0.5mm above and below the gold standard was chosen as the equivalence bounds based on previously accepted guidelines for measuring articulation accuracy.[16] A significance level of 0.05 and SAS EG v.6.1 were used for all analyses.

Results

The method showed a high inter-examiner and intra-examiner reproducibility. These results showed that the operators reproduced the measurements in a reliable and consistent way (Table 2). Operators also demonstrated similar means and variability when compared with each other (Table 3).

Table 2- Mean and Standard Deviation of Measurements Repeated within Operators

	Left Incisor mm ± SD	**Left Canine mm ± SD**	**Left Molar mm ± SD**	**Right Incisor mm ± SD**	**Right Canine mm ± SD**	**Right Molar mm ± SD**
Initial	(9.6 ± 0.2)	(8.3 ± 0.1)	(5.7 ± 0.2)	(10.3 ± 0.1)	(10.8 ± 0.2)	(5.4 ± 0.2)
Repeat	(9.7 ± 0.2)	(8.4 ± 0.2)	(5.7 ± 0.2)	(10.3 ± 0.2)	(10.9 ± 0.2)	(5.5 ± 0.2)

Table 3- Mean and Standard Deviation of Measurements for Each Operator

	Left Incisor mm ± SD	**Left Canine mm ± SD**	**Left Molar mm ± SD**	**Right Incisor mm ± SD**	**Right Canine mm ± SD**	**Right Molar mm ± SD**
Operator 1	(9.6 ± 0.3)	(8.2 ± 0.1)	(5.4 ± 0.2)	(10.1 ± 0.2)	(10.6 ± 0.1)	(5.2 ± 0.2)
Operator 2	(9.3 ± 0.2)	(8.1 ± 0.2)	(5.2 ± 0.1)	(10 ± 0.2)	(10.4 ± 0.2)	(5.2 ± 0.2)

The three software platforms resulted in measurements that were within the 0.5mm equivalence bounds used in this study (Table 4). The differences from the gold standard were negligible in all groups, and OrthoCAD™ software platform showed the least difference from the gold standard (Table 4).

Table 4- Equivalence of Software Platforms Used

Software	90% CL Mean (0.05 Significance Level Equivalence Test)	
Motion View	**(-0.21, -0.16)**	**Equivalent**
MeshLab	**(0.20, 0.28)**	**Equivalent**
OrthoCAD™	**(-0.07, 0.05)**	**Equivalent**

All experimental groups reported at least three inter-arch measurements that were within the clinically acceptable range of +/-0.5mm of the gold standard (Figure 4). Of the scanners tested, only the iTero® scanner and iTero® Element Scanner produced articulated models with all inter-arch measurements within the acceptable range (Figure 4). The 3M™ scanner and the Regisil® bite registration used with the extraoral OI3D scanner produced four of the six interarch measurements within the acceptable range (Figure 4). The Coprwax™ bite registration used with the extraoral OI3D scanner produced only three of the six inter-arch measurements in the acceptable range (Figure 4). The 95% equivalence bounds for all measurements and methods are presented in Figure 5.

In addition to equivalence testing, descriptive statistics were calculated to assess variability between articulations within each group (Table 6). Although all groups exhibited some variability, the Coprwax ™ group showed by far the largest standard deviation in every inter-arch measurement, which is consistent with the TOST procedure results (Table 5).

Table 5- Difference from Gold Standard (mm) and TOST Equivalence Bounds.

	90% CL Mean on Difference from Gold Standard in mm				
	Coprwax ™ (OI3D)	**Regisil® (OI3D)**	**iTero®**	**iTero® Element**	**3M™ Scanner**
Right Molar	(0.41, 0.87)	(0.33, 0.61)	**(0.2, 0.3)**	**(0.13, 0.32)**	**(0.28, 0.43)**
Right Canine	(0.07, 0.52)	**(0.29, 0.43)**	**(0.31, 0.4)**	**(0.09, 0.4)**	(0.48, 0.56)
Right Incisor	**(-0.2, 0.38)**	**(0.12, 0.24)**	**(0.16, 0.24)**	**(0.02, 0.17)**	**(0.25, 0.33)**
Left Molar	(0.14, 0.66)	(0.57, 0.73)	**(0.39, 0.48)**	**(0.19, 0.39)**	(0.44, 0.59)
Left Canine	**(-0.21, 0.31)**	**(0.15, 0.25)**	**(0.19, 0.27)**	**(0.07, 0.18)**	**(0.35, 0.43)**
Left Incisor	**(-0.36, 0.26)**	**(0.09, 0.24)**	**(0.11, 0.2)**	**(0.02, 0.16)**	**(0.23, 0.29)**

*Items **in bold** are statistically equivalent within +/-0.5mm of gold standard measurements based on TOST with a significance level of P < 0.05.

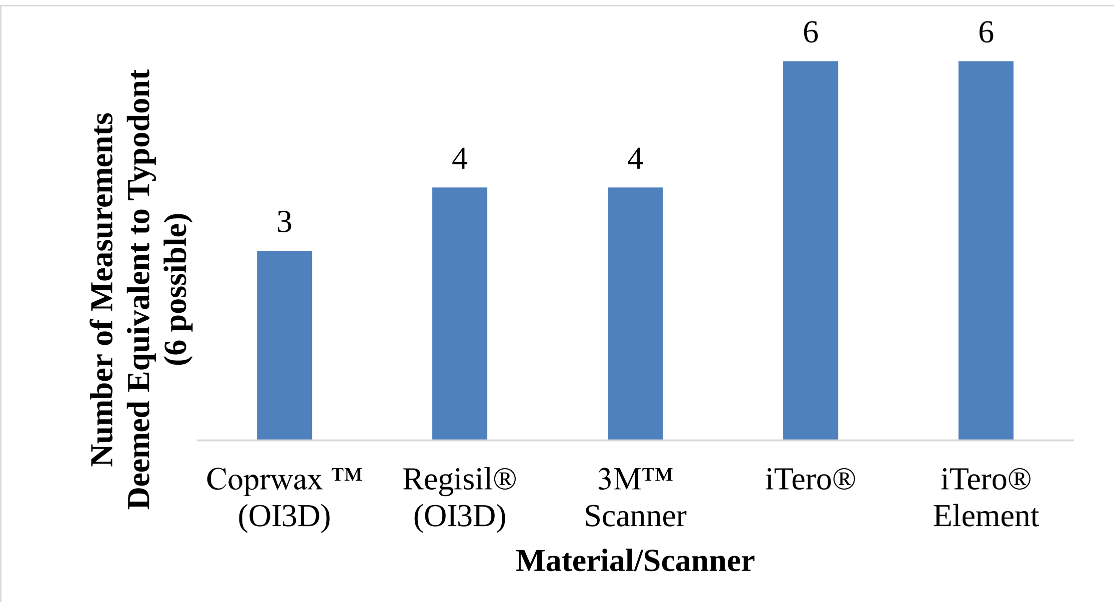

Figure 4- Number of Equivalent Inter-arch Measurements per Scanner

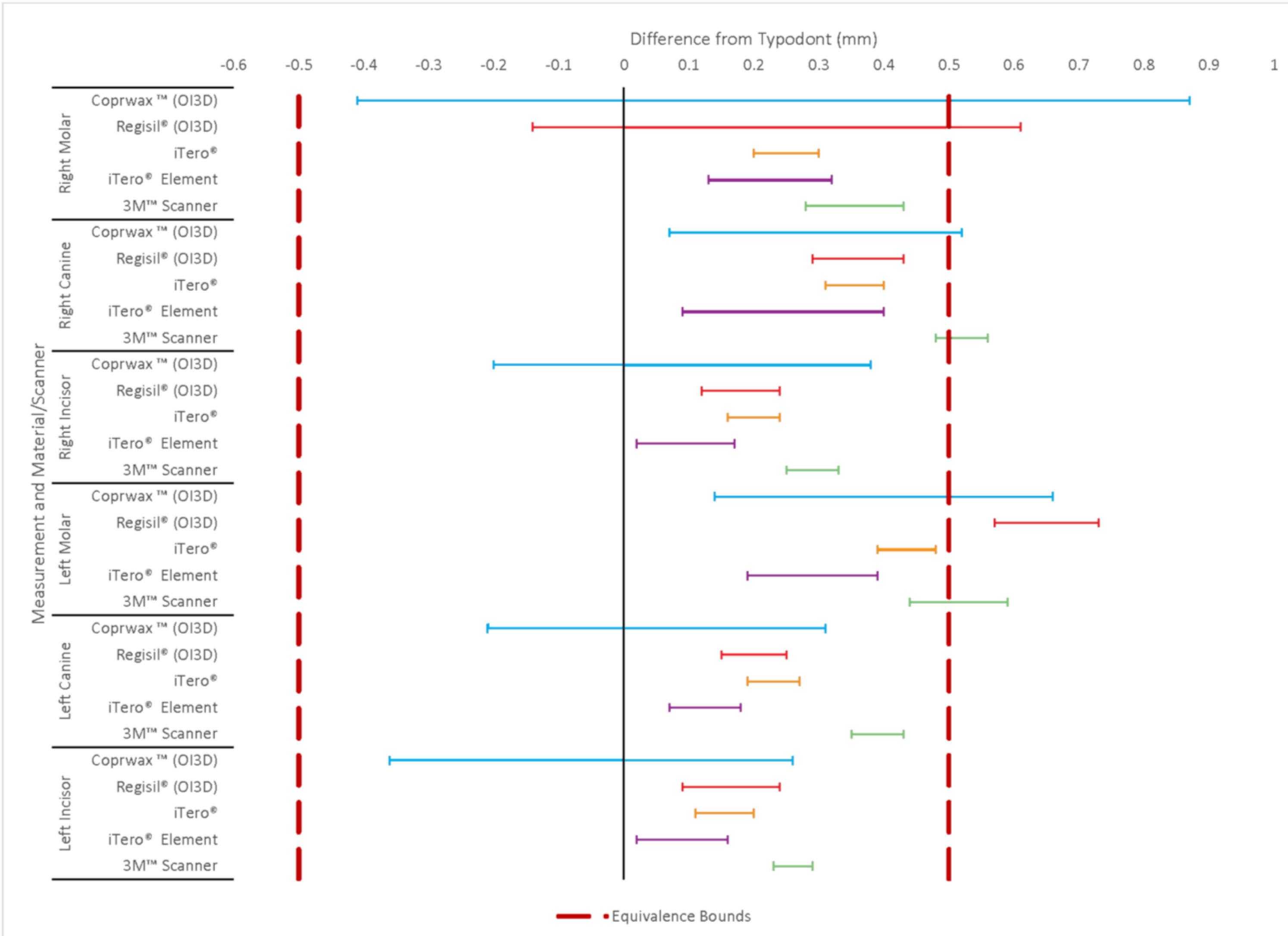

Figure 5- Difference from Gold Standard (mm) and TOST Equivalence Bounds. Each bar represents the 95 % equivalence bounds for all methods and measurements. Those that fall within the TOST equivalence bounds at 0.5mm from the gold standard are deemed equivalent to the gold standard.

Table 6- Mean and Standard Deviation of Each Measurement by Method

Material/Scanner	Left Incisor mm ± SD	Left Canine mm ± SD	Left Molar mm ± SD	Right Incisor mm ± SD	Right Canine mm ± SD	Right Molar mm ± SD
Gold Standard	9.5 ± 0.32	8.1 ± 0.16	5.3 ± 0.18	10.1 ± 0.19	10.5 ± 0.17	5.2 ± 0.19
Coprwax ™	9.5 ± 0.9	8.2 ± 0.76	5.7 ± 0.75	10.2 ± 0.85	10.8 ± 0.66	5.8 ± 0.66
Regisil®	9.7 ± 0.22	8.3 ± 0.15	6 ± 0.23	10.3 ± 0.18	10.9 ± 0.2	5.7 ± 0.41
3M™ Scanner	9.8 ± 0.09	8.5 ± 0.12	5.8 ± 0.22	10.4 ± 0.11	11 ± 0.11	5.6 ± 0.22
iTero®	9.7 ± 0.18	8.3 ± 0.17	5.7 ± 0.17	10.3 ± 0.16	10.9 ± 0.19	5.5 ± 0.20
iTero® Element	9.6 ± 0.2	8.2 ± 0.16	5.6 ± 0.29	10.2 ± 0.22	10.7 ± 0.44	5.4 ± 0.27

Discussion

In this study, standardized points were used instead of traditional measurements of overjet and overbite to increase the accuracy of measurements. Hayashi, et al. reported findings that employing a system of creating standardized measuring points decreases the random errors of measurements associated with identifying landmarks.[18] The inter-arch measurements from the standardized marks on specified teeth therefore served as accurate indicators of overall scanner accuracy.

The iTero® and the iTero® Element intraoral scanners produced the most accurate results overall with all six inter-arch measurements within the pre-selected equivalence bounds (Table 5). The iTero® scanner showed less variability than the iTero® Element scanner as shown in Table 6. The standard deviations of the iTero® Element were larger in all six inter-arch measurement groups when compared with the iTero® scanner (Table 6). This would suggest that, although both the iTero® and the iTero® Element intraoral scanners produce accurate articulations, the iTero® scanner may produce scans that are more consistent than the iTero® Element due to less variation in measurements. However, as the difference in standard deviations between the two scanners was very small, the clinical significance of the difference is questionable (Table 6).

The iTero® and the iTero® Element intraoral scanners are very similar with slight differences in characteristics. These scanners both do not require powder in capturing the digital images as is the case with the 3M™ True Definition scanner. These scanners do differ in the image acquisition characteristics as the iTero® Element scanner utilizes continuous scanning much like the 3M™ True Definition scanner and the iTero® scanner must be held motionless at the time of image capture. The bite capture procedure is similar for both scanners. The slight increase in variability for the iTero® Element intraoral scanner may be due to the motion that is introduced during the acquisition procedure when compared to the iTero® scanner.

The 3M™ True Definition scanner produced extremely consistent results as shown in the low standard deviation between scans (Table 6). However, these consistent results were only accurate in four of the six inter-arch measurement categories (Table 5). These findings would suggest that the manner in which the scanner and software combination articulates models does not represent the actual occlusion. This may be because the 3M™ True Definition scanner uses a powder to capture the image. The powder, although fine, could adversely affect the articulation. Another possibility is that the software used does not accurately mesh all scans together. 3M™ does not recommend any specific viewer for the models produced on their scanner. It is possible that there are other more accurate model viewers for 3M™ True Definition scans than the MeshLab software used. To fully determine the impact of the software various digital model viewers would need to be evaluated to determine if the use of other software results in more accurate occlusion.

The results of this research regarding the Ortho Insight 3D® (OI3D) laser surface scanner support the findings of other research on this topic showing that Regisil® bite registrations are the most accurate bite registration evaluated.[16] This study did not test all bite registration materials as many of these were tested in a previous study.[16] Coprwax ™ was selected for this experiment because it has been shown to be accurate using out of office digital model production companies and has not been investigated in conjunction with the Ortho Insight 3D® laser surface scanner.[17] As a whole the Ortho Insight 3D® (OI3D) laser surface scanner produced less accurate results than the iTero® and the iTero® Element intraoral scanners (Table 5).

The bite registration that was found to be most accurate when used with the Ortho Insight 3D® laser surface scanner was the Regisil® bite registration (Table 5). The Regisil® bite registration also resulted in less variability when compared to the Coprwax ™ bite registration as shown by smaller standard deviations (Table 6). The Regisil® bite registration may be superior to the Coprwax ™ due to a number of factors. The Regisil® bite registration is a PVS material as compared to the Coprwax ™ material that is a wax wafer with a thin aluminum sheet in the middle. The aluminum sheet may prevent the models from closing completely and may therefore result in more variability and a less accurate articulation. Another possible explanation of the difference in accuracy between bite registrations is that the Coprwax ™ is more sensitive to distortion due to temperature change. This is unlikely due to the very controlled handling of the Coprwax ™ described in the Materials and Methods but, in clinical practice, the distortion of this material may be more of a factor. A third possible explanation for the difference in articulation accuracy between bite registrations is that the laser reader used in the OI3D may read the PVS material in a more accurate manner. These factors would need to be considered, along with cost, in the clinician's choice of which bite registration to use with this scanner.

The software platform accuracy may also affect the accuracy of the model articulation. The Ortho Insight 3D® laser surface scanner groups may both show some slight inaccuracies when compared with the gold standard due to the software ability to mesh as previously stated with the 3M™ True Definition scanner. Although the three software platforms all were within the equivalent bounds there were slight differences between the software platforms (Table 4). The OrthoCAD™ software was shown to produce more accurate representations of the scan than the other software utilized by other scanners. The increased accuracy factors in some degree for the iTero® and the iTero® Element intraoral scanners being more accurate as they both utilize the OrthoCAD™ software. Perhaps 3M models or OI3D models viewed with a more robust software system would produce more accurately rendered digital models.

The practical usage and workflow of the scanners should also be assessed when determining which scanner would be of benefit to the provider. The Ortho Insight 3D® (OI3D) laser surface scanner groups rely on a physical bite registration that must be transferred from the mouth of the patient to the scanner. This extra step results in extra time requirements on staff and may result in slight distortions that would not occur with the direct intra-oral scanners simply because of the eliminated step. The slight distortion on transfer may be the contributing factor to the difference in accuracy between the iTero® and the iTero® Element intraoral scanners and the Ortho Insight 3D® (OI3D) laser surface scanner.

Conclusions

- The iTero® and the iTero® Element scanners produced the most accurately articulated models with the setup used in this study. The 3M™ True Definition scanner and Ortho Insight 3D® laser surface scanner with Regisil® bite registration were the next most accurate scanning method of articulating digital models. The Ortho Insight 3D® laser surface scanner with Coprwax ™ bite registration was the least accurate method of articulating digital models.
- The OrthoCAD™ software was the most accurate software platform used for measuring objects on digital casts of those tested in this study. All software platforms did however produce acceptable measurements when evaluated with regard to the equivalence bounds set in this study.

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