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Grado en Odontología

INFLUENCING FACTORS OVER THE ACCURACY OF INTRAORAL SCANNERS: SCANNING PROTOCOL AND OPERATOR EXPERIENCE.

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Resumen:

En este artículo se repasan los diferentes factores que pueden afectar a la veracidad de los escáneres intraorales, bien sea debido a los materiales que estamos utilizando o por el operador. El objetivo es poder entender qué podría favorecer o reducir el rendimiento de nuestros escáneres para mejorar los resultados finales de nuestros flujos de trabajo.

- Objetivos:

Este estudio se ha orientado hacia la comprensión del concepto general de la exactitud de los escáneres intraorales, sus indicaciones, el propósito real de los diferentes protocolos de escaneo sobre la exactitud de estas dichas máquinas y también el efecto de la experiencia del operador sobre estas.

- Metodología:

La búsqueda del material se realizó a través de bases de datos científicas como son "Medline", "Cochrane" y "Mendeley" para asegurar una bibliografía con evidencia científica y actualizada. No se incluyeron casos clínicos por ser difíciles de reproducir y por carecer de evidencia científica. Un total de 29 estudios llegaron a la bibliografía final. Palabras clave como: "intraoral" "escáneres", "CAD/CAM", "precisión", "operador", "escanear" "protocolo", "digital", "influencia", "experiencia", "escanear" cuerpos" fueron utilizadas.

- Resultados:

Los resultados de este trabajo fueron encontrados en diferentes artículos con una antigüedad de 5 años o menos.

- Conclusión:

Múltiples factores pueden afectar a la exactitud general de los escáneres intraorales, hemos visto que muchos de los factores que influyen negativamente pueden ser eliminados o al

menos controlados para poder mantener una exactitud aceptable. Se han extraído algunas conclusiones alentadoras e inesperadas, como el hecho de que el nivel de experiencia del operador no afecta realmente a la precisión general del escaneado final y que el protocolo de escaneado desempeña un papel clave sólo en algunos modelos. Podemos recomendar el uso del protocolo de escaneado indicado por el fabricante, ya que no se han encontrado discrepancias particulares entre las distintas técnicas. El diseño asistido por ordenador y la fabricación asistida por ordenador han evolucionado enormemente y todavía tienen un buen margen de progresión que podría corregir los pocos fallos encontrados.

Abstract:

This paper is going over the different factors that could potentially affect the accuracy of intraoral scanners, either being induced by the materials we are using or by the operator. The aim is to be able to understand what could increase or reduce the performance of our scanners in order to improve the final results of our workflows.

- Objectives:

This study has been oriented toward the understanding of the general accuracy concept of intraoral scanners, their indications, the real purpose of the different scanning protocols over the accuracy of those machines as well as the operator's experience effect over it.

- Methodology:

The material was searched through scientific databases like "Medline", "Cochrane" and "Mendeley" to ensure a bibliography with scientific and updated evidence. Clinical cases were not included because they were difficult to reproduce and lacked scientific evidence. A total of 29 studies were included in the final bibliography. Key words such as: “intraoral” “scanners”, “CAD/CAM”, “accuracy”, “operator”, “scanning” “protocol”, “digital”, “influence”, “user”, “experience”, “scan” bodies” were used.

- Results:

The results from this paper were taken in different articles being 5 years old or less.

- Conclusion:

Multiple factors can affect the overall really performant accuracy of the intraoral scanners, we have seen that a lot of the bad influencing factors can be removed or at least controlled to be able to maintain an acceptable accuracy. Some encouraging and unexpected conclusion have been drawn like the fact that the operator's experience level doesn't really affect the

overall accuracy of the final scan and that the scanning protocol plays a key role in only a few models. We may recommend if anything, the scanning protocol given by the manufacturer as no particular discrepancies were encountered in between the different techniques. Computer aided design and computer aided manufacturing have made a huge evolution and still have a good progression margin that might correct the few flaws encounter.

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1. Introduction:

During the 20th century, dentistry has seen a huge amount of progress in all its domain. Particularly with the arrival of computer-aided design and computer-aided manufacturing technology that we will refer as CAD/CAM Technology. Computer assisted processing technology existed since the 1970s in many industries.(1) Research and development of CAD/CAM in dentistry started in the 1980s with the manufacturers thinking wrongly that it would be simpler to do than the previous applications CAD/CAM had already seen. Effectively, dental restorations demand a high accuracy in order to avoid future problems like marginal filtration leakage and the lack of passive interactions between the prosthesis and the teeth or implant. The clinically acceptable value for marginal discrepancy in a CAD/CAM restauration has to be between 50 and 100 µm for a full coverage crown.(2,3) Nowadays, using a different technique, we are even able to scan and digitally prepare an implant supported crown.(4) This technique consists of scanning a “scan body” instead of the prepared tooth. This scan body is placed over the implant (using the implant connection) in order to give the necessaries landmarks needed to create the 3D model to the software. For implant fixed dental prosthesis there is a consensus that a marginal misfit of 120 µm is acceptable.(5)

There is a common misconception around the word “accuracy”, thus, it is necessary to start by clarifying this term. Precision and accuracy don’t have the same meaning. If we look into the dictionary, accuracy corresponds to being true, exact or the absence of error. On the other hand, “precision” is all about the consistence of those results, the ability to have repeatable results. Ideally it looks like it would be better to have both combined, particularly when talking about a scientific element. This is where the ISO (International Organization of

Standardization) comes in with their definition: "The closeness of agreement between a test result and the accepted reference value" (*ISO 5725-1:1994*) where we can find that accuracy is described by "trueness" and "precision" at the same time. Accuracy has much more scientifical relevance as we are now looking for results that are true and that are repeatable at the same time.

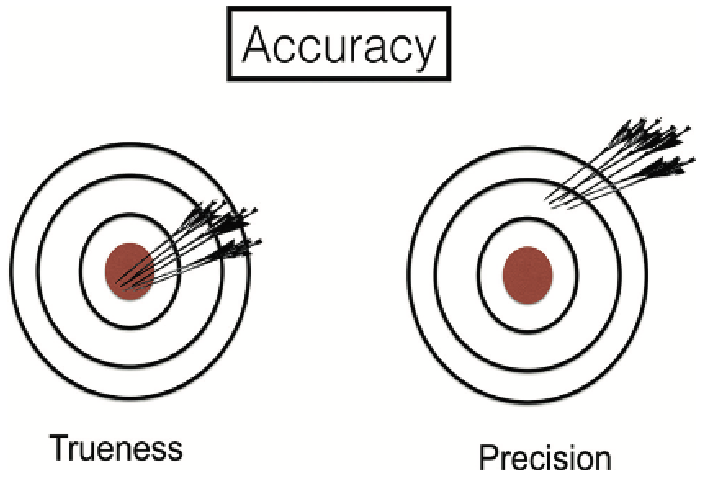

Figure 1: Image representation of the accuracy definition. (6)

Now that this technology can be find in more and more dental offices, with the really satisfying results it has, considering that in some cases we can even reduce the amount of appointment compared to the conventional methods, it is needless to say that it has revolutionized our daily practice, particularly in the prosthodontic domain but also in the orthodontic and surgery one.(6)

Multiple companies have been working on these products trying to get the CAD/CAM combo faster, easier to use, more intuitive with a permanent amelioration in terms of definition and accuracy. From now on, we will refer to intraoral scanners as "IOS".

The manufacturers that came out more often during the writing of this paper where: Sirona®; 3M® and Cadent®. Those companies sell intraoral scanners, milling units and some companies even propose their CAD software that is making the link between the scanner and the milling unit, which we will see, have a major role in the overall final accuracy. (7) The software can either be made by the same brand as the CAD/CAM system, those are then called "closed systems" as the brand is at the two ends of the chain. This also means that it is exclusively reserved to work with the brand's ecosystem. If the software isn't made by the same brand, this is called an open system that, on the contrary of the previous one, can be used with any CAD/CAM set.

Intraoral scanners have different technologies depending on the brand and the model. First of all, the aim of an intraoral scanner is to build a 3D representation of the object in order for the operator to be able to work on it digitally. It consists of building a 3D surfaces by using a point cloud that is projected and scanned by the device. The device recognizes the point cloud and register the number of points present on the surface. Then, it connects each point by 3 connections with the adjacent points, thus creating a net of triangles. Once this is done, the software is now able to recreate the scanned object as it is placing back the points and triangles togethers in the correct order using the stored dimensions. This 3D representation will be stored as an STL file (standard tessellation language) that will then be opened on different software.(8)

Technically the scanner needs a system to project light on the surface that we want to scan and then an imaging system to record it. Here we start to have multiple options that have proven to be working and that are used by the manufacturers: (9,10)

	Open/close system	Color matching	Portable	Type of CAD/CAM	Acquisition technology	Powder required	Color image	Imaging type
CEREC Omnicom (Sirona)	Closed	No	No	Digital imaging and in-office manufacturing	White light	No	Yes	Filming (Video)
PlanScan (Planmeca)	Open	No	Yes	Digital imaging and in-office manufacturing	Blue Laser	No	No	Filming (Video)
Trios Color (3 Shape)	Open	Yes	Yes	Image acquisition unit	Blue LED	No	Yes	Photographing (multiple images)
iTero (Align Technology)	Open	No	No	Image acquisition unit	Red Laser	No	Yes	Photographing (multiple images)
True Definition Scanner (3M ESPE)	Open	No	No	Image acquisition unit	Blue LED	Yes	No	Filming (Video)
CS 3500 (Carestream Dental LLC)	Open	No	Yes	Image acquisition unit	White LED	No	Yes	Photographing (multiple images)
Apollo DI (Sirona)	Closed	No	No	Image acquisition unit	NA[a]	Yes	No	Filming (Video)

[a] NA = information not available.

Figure 2: Comparisons of different in-office CAD/CAM systems. (10)

It used to be more current when this technology appeared, but it is still an actual subject. Some of the scanners need a mandatory upstream application of powder (also called "scanning aid") over the surfaces we want to scan (although, if desired, the powder could be used with any of the other scanners). The ambient light or the one produced by the scanning device could produce a reflection over the tooth or the scanned abutment. That could lead to a scanning error. Therefore, the goal of this powder, composed of titanium dioxide (TiO_2), is to mattify the targeted surface in order to remove the potential light reflection, leading us to an ideal post scan result, also called, "digital workflow".(11) Another way of applying TiO_2 also exist and it is called, liquid scanning aid. Instead of being a powder spray it is applied like a varnish. The potential downside of using those accessories is that we won't be able to use the color selection tool that will be developed in the next paragraph. A dedicated section of this paper will investigate over the potential effects of those type of scanning aid, in order to see if they have any role around the accuracy results.

Another characteristic that we could find in IOS units would be the “colored images”. When used with the correct software and a previous calibration, it aims to give us the tint needed for our restoration.(12) Compared to the naked eye, this system can give us the different hidden tones that are present throughout a single tooth surface, making the color selection process more accurate.

Finally, some manufacturers give the choice or not to either use their proprietary software or an external third party STL file software. We will also address the effects of this choice over the accuracy.

Each manufacturer gives a sequence to follow in order to have the best results possible, once again, a full section in this paper is dedicated to this subject, as it is one of the most important fragments of the “scanning protocol” part.

Finally, it is important to note that in the case of a tooth preparation, the impression will be realized over the prepared tooth directly. As far as scan bodies for implant impressions are concerned, each implant company manufacture their own units in adequation with the IOS companies. A lot of them already exist and they might not all be equal in term of results.

2. Objectives:

The main objective is to determine:

- The general accuracy of intraoral scanner and it's indication.

The secondary objectives are to determine:

- The relevance of the scanning protocol on the accuracy of those intraoral scanners.
- The relevance of the operator's experience on the accuracy of those intraoral scanners.

3. Materials and Methods:

This study was made only by using published articles in order to have the best scientific relevance possible. 29 articles were used to write it. The oldest publication is dated from 2009 for historical background research only. The rest of them are spaced out over the course of the last five years, starting from 2015 to 2020, the year this paper was written.

Key words such as: “intraoral” “scanners”, “CAD/CAM”, “accuracy”, “operator”, “scanning” “protocol”, “digital”, “influence”, “user”, “experience”, “scan” bodies” were used. Close to no exclusion factors were used apart from the exception that, clinical cases were avoided as they have one of the lowest scientific evidence and that they are not repeatable. In-vitro and in-vivo studies were both of them selected as well as implant related and/or natural teeth studies. The selected articles on the other hand were extracted from reliable databases like “Medline”, “Cochrane”, “Mendeley” mostly using the “advance search” tool.

4. Results and Discussion:

This discussion will be built in 2 main units, each of them divided in subsections. The first one will contain the non-operator dependent factors affecting the accuracy of intraoral scanners and the second one will cover the operator dependent factors affecting the accuracy of IOS. This structure will help us to reach our objectives. A precision has to be made about the "discrepancy measurements"; in all the articles where it was measured, the protocol was the same and consisted of making a preliminary scan with an industrial scanner (considered as the gold standard in term of accuracy) that corresponds to the "control scan", also called, the reference. Then the scans from the IOS were taken and compared using different CAD software, giving the different charts, tables and values to analyze.

4.1 Non operator dependent:

4.1.1 Oral environment:

The oral medium is notorious for being a hostile environment to work with, both microscopically and macroscopically.(13) Here, the aspects that interests us the most are at the macro level since they are the ones that could interfere with the accuracy of our intraoral scanners and be measured. We will talk about elements such as saliva and blood, the opening amplitude and the anatomic limits we could encounter.

4.1.1.1 Blood and saliva:

They are elements that are practically always present while we are working in the mouth, particularly the saliva. In some cases when making juxta or sub-gingival preparations for example, it will be joined by the presence of blood, forcing in some cases, the use of preliminary isolation when possible or when it's not, some waiting time in between appointments in order to get a good impression. So far, with the current impression materials we wanted to avoid them a maximum as the impression materials tended to be hydrophilic and with the presence of liquids in the mouth, there would be a discrepancy between the tooth preparation and the final model.(14) Unfortunately, for intraoral scanners so far, they are also prone to discrepancies in the presence of blood or saliva due to the light refraction effect:

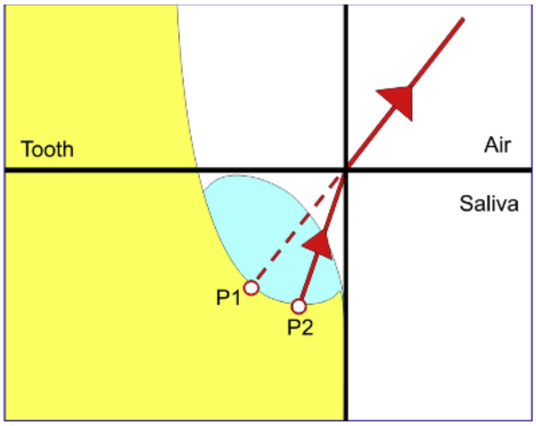

Figure 3: schematic representation of the refraction effect. (P1= predicted point, P2= real point)(15)

As all the IOS on the market use a system based on collecting data threw light reflection

so far, they are subjected to this error, thus, we will see some discrepancies that could go up to 1.5mm which in the oral cavity are considered too Large to be accepted.(16) This effect can even be seen over the 3D representation of a scan. (figure 4)

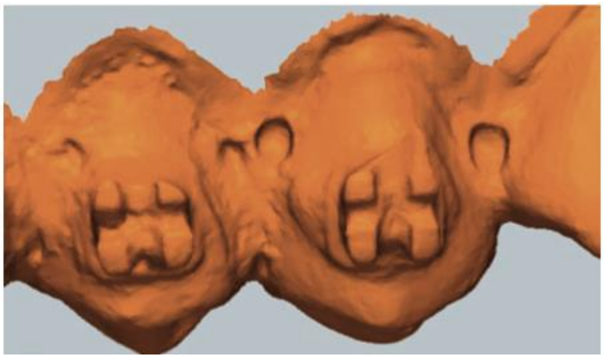

Figure 4: image of a 3D model scanned with saliva. (16)

On figure 4, we can observe that bubbles have been represented by the system as a concave surface rather than a convex one. The presence of such errors over the working model makes the manufacturing process too hard and unstable for achieving a good fit of the prosthesis. Considering this information, we could say that IOS have to be used with care in the presence of body fluids such as blood and saliva, because in some cases, due to the light reflection's behavior unpredictability the results might get far off acceptability. (16)

In the article from Camci H and cols where they studied the effect of saliva over the performances of an intraoral scanner by comparing a scan with the presence of saliva to the controlled scan, where isolation was used, they explain that it is difficult to predict whether the deviation would be positive or negative due to the different environmental conditions as scanning the mouth without isolation gave different discrepancies every time. They founded that saliva alone could cause up to 13% deviation, potentially making the result far off the acceptable limit. (15)

4.1.1.2 Access and range:

The oral environment also has other obstacles to offer due to its shape as some articles have proven that some parts of tooth anatomy are harder to access than others. (7) Having an accurate full arch impression have been proven to be harder to obtain accurately than a smaller arch sections.(17) The accuracy decreases as the arch gets bigger. This can be encountered in the article from Giménez B and cols working on the accuracy of a digital impression system and explained by the fact that the system makes a lot of overlap throughout the scan to put all the pieces back together, leading to some error.(18)

Nedelcu R and cols when testing the accuracy and the precision of 3 different intraoral scanner over conventional ones went further into the explanation of the origins of this phenomenon. These errors caused by “overlapping” are linked to the unattached surrounding tissues of the scanned teeth that are taken into the data (see figure 8). If there is any movement of those, in between the different measurements, even a slight shift, it could cause an improper stitching of the scan.(19)

In other words, as the scanner head can’t take the hole arch in a single frame, it needs to build it from multiple smaller ones. In order for the IOS to do that, it is permanently taking reference points. If there is a movement of these reference points, in the case one or more would be over those tissues, when building the final image, it will have some errors in it. This brings us back to Gimenez B and cols conclusion that we could adapt saying that the less potential moving reference points we have the better will the results be.(19)

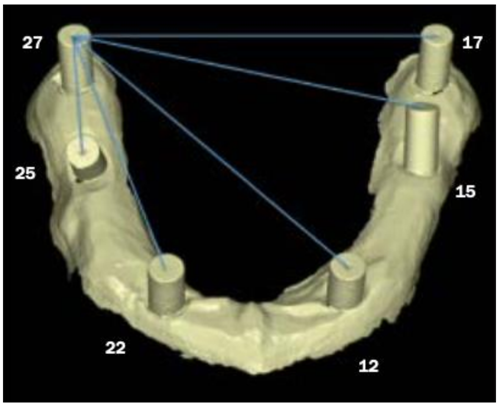

Figure 8: Picture of an arch with implant abutments.(9)

As far as tooth surfaces are concerned, the scanning accuracy of each one of them have been put to the test by Chiu A and cols with their study comparing CAD/CAM accuracy using different intraoral scanner settings. It proved to be significantly affected by them. As showed on figure 5, the surface with the highest discrepancy came out to be the Distal one, whatever the chosen resolution.(7) Not only it is the one with the highest discrepancy, but it is doing it by more than twice the amount that some of the other surfaces have.

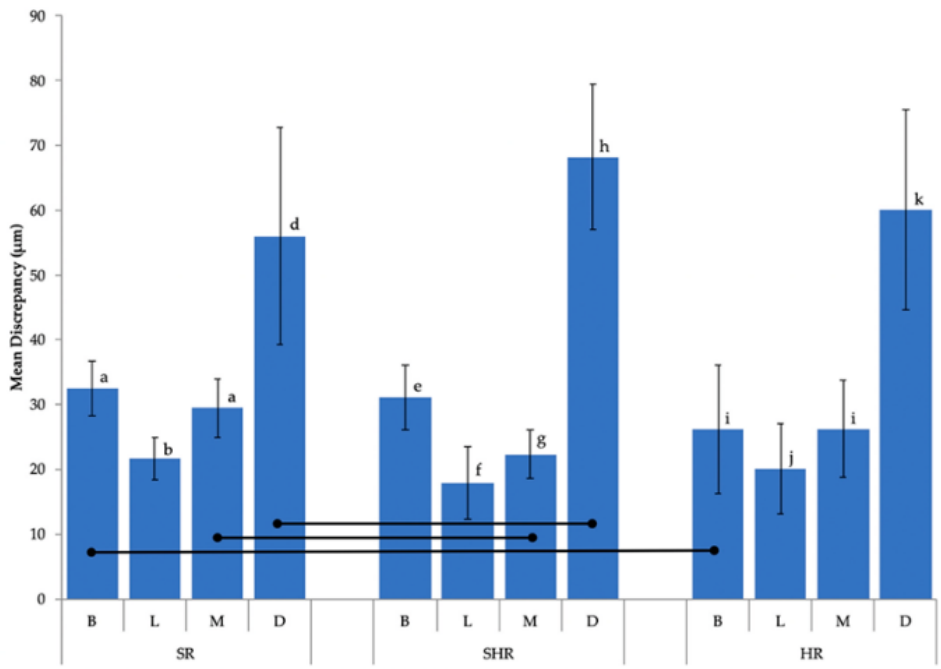

Figure 5: Vertical bar chart representing the mean discrepancy in µm over a finish line preparation.(7)

Special care to this distal area, particularly when working on posterior teeth, might be necessary in order to avoid worsening this already important discrepancy.

4.1.2 <u>Software & models:</u>

This section will address the effects over the accuracy when using different software, modes and even different intraoral system brands as some interesting studies have shown that not all of them are equal. (7,8,20,21)

4.1.2.1 Software:

They are the keys of the CAD/CAM world as they are linking the two ends of the chain. They receive the cloud point from the IOS, transform it into an STL file, they let us create and modify the design of object we want to create and then, they send all the orders to the milling device in order to create a physical object in the desired material.

Multiple resolutions can be used when using a scanning device, we will try to understand what makes the difference between each other's and see if they can have any effect over the accuracy.

From the encountered studies, the difference between the different resolutions would be that the higher the chosen definition, the more images are necessary, therefore, they are filling a bigger storage file. In order to make that, the high resolution (HR) takes more time than the standard resolution (SR). Figure 5 also illustrates the results obtained measuring all teeth surfaces with 3 different resolutions. The conclusion from this study wasn't the one expected as the highest resolution didn't necessarily got the best results (the lowest discrepancy).(7,20) The longer time required, and the higher number of images might have been working against the intended purpose.

Now that we have seen how the software compares against itself in his different parameters, we will now have a look at comparing the different software, particularly the ones branded by the manufacturers and the open access ones.

It was important to determine whether we should be using the branded software of our IOS or not. Studies have compared IOS brands between each other's and at the same time, using different software. The conclusion was clear, using the CAD software associated with the IOS by manufacturers exhibit less discrepancy than using an open software.(8,21)

INTRAORAL SCANNER-CAD COMBINATION	INTRAORAL SCANNER USED FOR COMBINATION	DATA FORMTION TRANSFORMATION	CAD SOFTWARE USED FOR COMBINATION
Omnicam Ac-inLab	Omnicam Ac 	No format transformation direct proprietary format	CEREC inLab SW 4.4.4
Omnicam Ac-exocad	Omnicam Ac 	Proprietary format → STL format	Exocad 2018
Trios 3 color-trios design studio	Trios 3 color pod 	No format transformation direct proprietary format	Trios design studio, dental system 2017
Trios 3 color-exocad	Trios 3 color pod 	Proprietary format → STL format	Exocad 2018
Aadva Ios-exocad	Aadva Ios 100 	No format transformation direct STL format	Exocad 2018

Figure 6: table of the combo used by the study to record the data.(8)

Thanks to this study from Erozan C and cols where they evaluate the precision of different intraoral scanner-computer, we are able to understand why the results are less satisfying when using an open software than a closed one. It is due to the conversion from the "proprietary format" to the "STL format". During this process there is a loss of data, conducting to discrepancies. There is no way to correct that right now because, as we saw, the STL format is the way that CAD/CAM files can be used and worked on.

This situation might force the laboratory team and dentist to unify their systems in order to obtain the best results possible as working on different platforms have proved to be less accurate.

4.1.2.2 Scanners:

This section is dedicated to the scanners themselves and their capacity to be accurate or not. In this section, we will try to see if there are differences in accuracy in between the different units, keeping in mind that the results were encountered in studies with different approaches than those made by the manufacturers and that some results may not be representative of the quality.

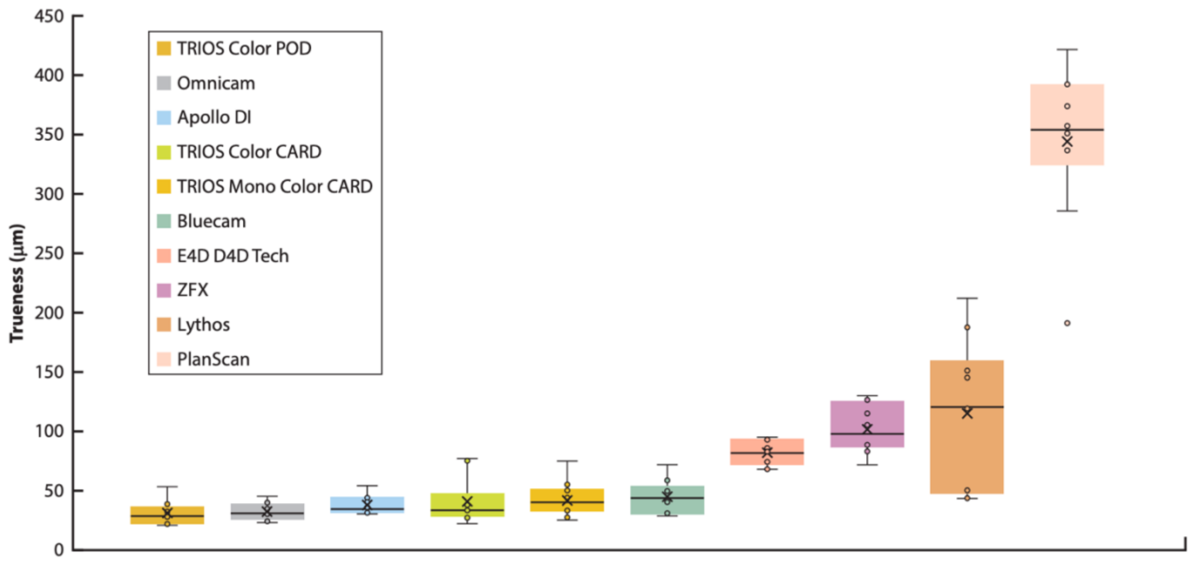

Figure 7: Deviation data of 10 different Intraoral scanners.(22)

These results obtained by Bilmenoglu C and cols in their study comparing the trueness of ten intraoral scanners have been obtained under similar conditions, meaning they were done *in vitro* over a model poured from a Kavo® typodont with ten different scanners. As we can see, in general there is a good uniformity of results. Over those ten tested IOS, seven are consistently under 100 µm of discrepancy which would permit us to do fixed prosthesis over implant as well as tooth supported without any particular risk, as we said that the upper limit is 100 µm of discrepancy for a full coverage crown and 120 µm for implant fixed prosthesis.(2,3,5)

4.2 Operator/ choice dependent:

This part of the work will be dedicated to the factors affecting the accuracy on which the operator could have an impact. We will talk about the operator's experience overall, the protocols we can choose to follow and their impact over the accuracy. Here a multitude of criteria have been taken into account in order to have all the keys to understand what could affect, reduce or enhance the accuracy we could reach using IOS systems.

4.2.1 Implants and their affectations over the IOS accuracy:

4.2.1.1 Scan bodies:

In dentistry, making an implant impression has always been slightly different than making one over a natural tooth. It is true for the conventional impressions as well as the digital ones. In the introduction, we've seen the existence of implant scan bodies (ISB) that have to be placed over the implant in order to act as a clear reference for our IOS.

Mizumoto RM and cols, in their study over intraoral scan bodies, tell us that part of the good accuracy results obtained by those ISB are explained by the fact that they have multiple scan areas (see figure 8) compared to a conventional cylindrical abutment that have less surface area.(23) Furthermore, they can also be made of different materials such as PEEK (Polyétheréthercétone) or even various resins that are less reflective thanks to a mattified finish than what would be a bare titanium classic abutment. To confirm this last point, Bilmenoglu C and cols found out, when comparing different IOS, that implant collars made of titanium could reflect the light of the scanners, therefore appearing as an artifact on the final 3D image, reducing the overall accuracy.(22) In this case, titanium doesn't have the advantage over the other materials like PEEK. According to the readings, the ideal abutment should have a multifaceted shape in order to present multiple scan areas and it should be made of a non-reflective material, such as the previously mentioned PEEK.

Figure 8: Picture of different scan bodies present on the market.(23)

4.2.1.2 Implant scanning sequence:

Once again digital impressions are following the guidelines of conventional ones, so there is also the possibility of making a one-step impression (scanning both the arch and the integrated scan bodies) or a two-step impression (make a first scan of the ridge, add the scan bodies and scan it once over to complete the 3D image). These 2 steps aim at getting better emergence profile out on the digital workflow. Trying to know if whether or not one was better than the other was the goal of a study made in 2019 by Motel C and cols where they've compared those two techniques *in vitro* and took different measurements.(24)

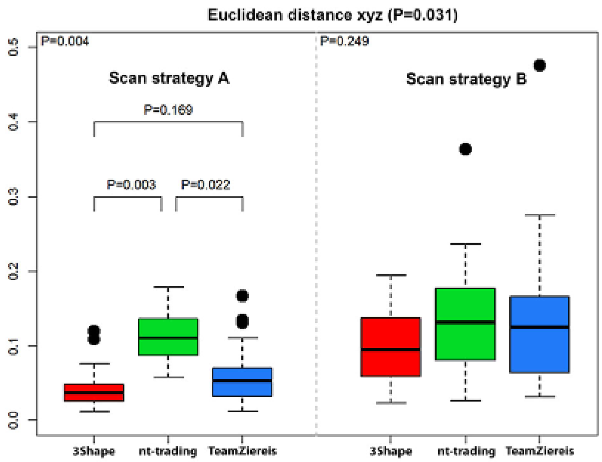

Figure 9: Box-whisker-plots of deviance of the 2 scan strategies over 3 different ISB(24)

Overall, by looking at figure 9 and following the study's conclusion, the one-step strategy proved to be more accurate than the two-step one. Although, it is important to note that both were well under the exigent accepted discrepancy set in the case of this particular study at 44 µm.(24)

4.2.1.3 Implant positioning and its potential IOS affectations:

Here, we will focus over two aspects of the implant placement, one will be the angulation and the other one will be the deepness. To be able to discuss this subject, we will use an article from Gimenez B and cols that wrote about the accuracy of digital impression systems where the goal was to experiment what could be the effects over the accuracy of a digital impression system under different clinical conditions, such as misplaced or misoriented implants for instance. In the paper, it is clear and favorable for the IOS that as far as the angulation is concerned, there are no significant discrepancies.(18) On the other hand, for the implant's depth, the results were that placing an implant at 0mm gets less accurate numbers than placing it at 2 to 4mm subgingival as shown on figure 10.

Table 3 Errors in Implant Distance with Different Implant Depths

Implant depth	No. of measurements	Mean (μm)	SD	Lower	Upper
0 mm	60	–23.1	149.485	122.318	190.924
2 mm	20	–16.2	34.569	24.829	55.344
4 mm	20	–27.9	61.643	44.276	98.690

Figure 10: table presenting the errors in implant distance with different implant depths.(18)

These results led to further investigations in order to understand the cause of this discrepancy and it was found that the implant depth in itself wasn't the direct cause of the error, but it was a collateral damage of the overlap made by the system, bringing us back to the same results from the first part of the discussion, where we said that an increased scan section length was detrimental to the truthiness of the scan.

4.2.2 The operator's related effects over the final accuracy:

In this section we will have a look over the studies that have taken into account the person manipulating the intraoral scanner, that when doing so, is called "the operator", in order to see if whether or not the machine in itself could performed differently whenever it is placed in different persons hand, thus, being subjected to more or less agility (experience related) and subjective decisions. Thanks to different studies that have already been looking into the user-friendliness of those systems, we have been able to come out with some conclusions about this question.

4.2.2.1 Scan strategies' choice:

As we have seen in the previous sections, in order to have a completed scan, the operator will have to go over the teeth by moving the IOS inside the patient's mouth. Some manufacturers and users have been subjecting different ways of doing those so called "scan strategies" like presented in figure 11.

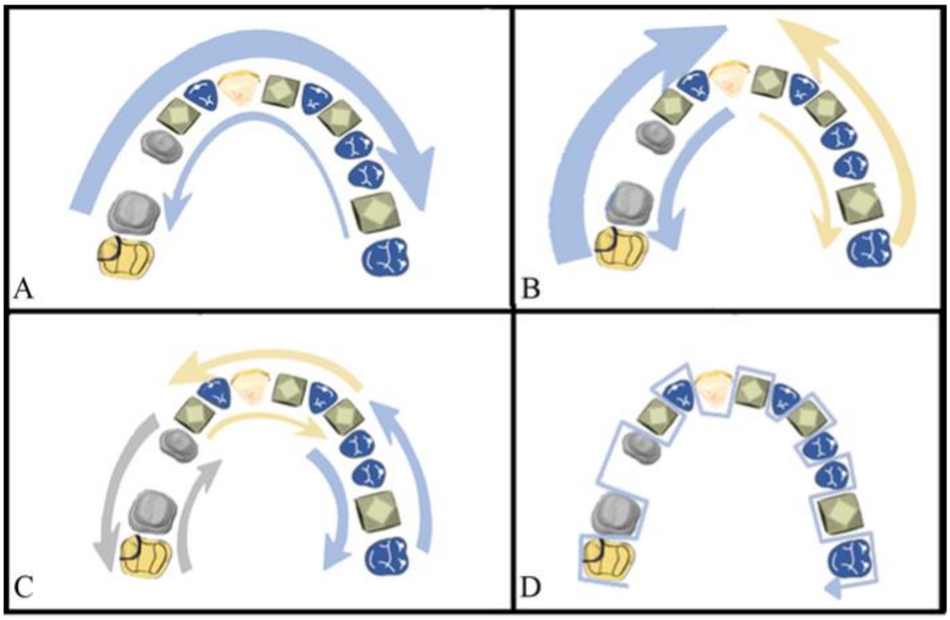

Figure 11: Schematic representation of different possible scan strategies: (A)Exterior-Interior, (B)Quadrants, (C)Sextants, (D)Sequential. (9)

As Figure 11 is coming from this article, we are going to start by discussing about the results encountered in this study from Sotomayor M and cols that was realized comparing different scan strategies. Furthermore, a nuance was added as four IOS are used in order to have representative results. The brand used were 3 shape® (Trios), Cadent® (iTero), Sirona® (Omnicam) and 3M® (True definition)

	Scanning strategy	N	Mean (SD)	Median	SD	Minimum	Maximum
Trios	A	10	184.51*	184.09	10.75	167.15	198.55
	B	10	194.53	193.81	7.22	181.53	205.47
	C	10	193.28	194.00	8.30	175.21	202.45
	D	10	205.79**	207.85	10.36	187.54	218.62
iTero	A	10	269.84**	251.06	53.96	210.03	391.69
	B	10	272.21**	267.84	29.95	231.29	311.30
	C	10	248.04**	240.86	15.92	233.64	283.84
	D	10	197.16*	198.49	25.57	157.17	246.49
Omnicam	A	10	260.12	275.21	36.23	209.95	299.87
	B	10	243.68*	236.24	35.63	191.23	307.49
	C	10	259.52	252.81	23.91	232.79	294.70
	D	10	283.73	278.19	23.32	253.29	327.42
True Definition	A	10	109.83	88.25	48.95	64.89	209.94
	B	10	111.78	90.35	44.15	73.91	203.24
	C	10	90.79	81.30	37.61	59.47	193.31
	D	10	82.83*	79.38	24.88	56.64	132.36

Figure 12: table of the precision data in µm from Sotomayor M. study.(9)

The study was realized over the same opaque epoxy resin cast, doing the same number of scans (10) for every strategy. It is important to note that those scans were considered long span because a complete arch was registered every time. What came out from this study was that apart from the Cadent® IOS, the scan strategies didn't have a significant influence over the accuracy of the other IOS. For the iTero, the sequential strategy proved to be the best one in this particular condition.(24)

Another study conducted 2 years earlier by Müller P. and cols, using a similar study design than the one mentioned before, pulled out slightly different result. They compared a total of 3 different scan strategies being: A: exterior-interior, B: interior-exterior, C: sequential (figure 13). Here the results turned out being slightly more favorable for the strategy B (starting from occlusal), but it is not an absolute criterion as the difference is close to being negligeable. It is mentioned that it "may" be advisable for full arch workflow.(25)

Figure 13: Illustrations representing the 3 scan strategies used in Muller P and cols study.(25)

To cloture this section, it is safe to say that so far, there isn't a consensus about which scan strategies should be used over the others, but it is clear that in long arch span scan, in certain cases some discrepancies might appear. Using either the manufacturer's recommended one or the operator's most comfortable one can be advised, particularly when working on smaller sections where the scan strategy doesn't have much importance.

4.2.2.2 Experience effect:

The question for this part is whether or not an experienced operator can achieve a better scanning accuracy than a novice. It is worth noting that in order to start noticing a "learning curve" and being considered with the minimum amount of experience, it is necessary to do at least around fifteen to sixteen scans if we follow the manufacturers words.(18)

In the article we've seen previously about the Accuracy of digital impression systems from Gimenez B and cols, differences between operators were encountered:(18)

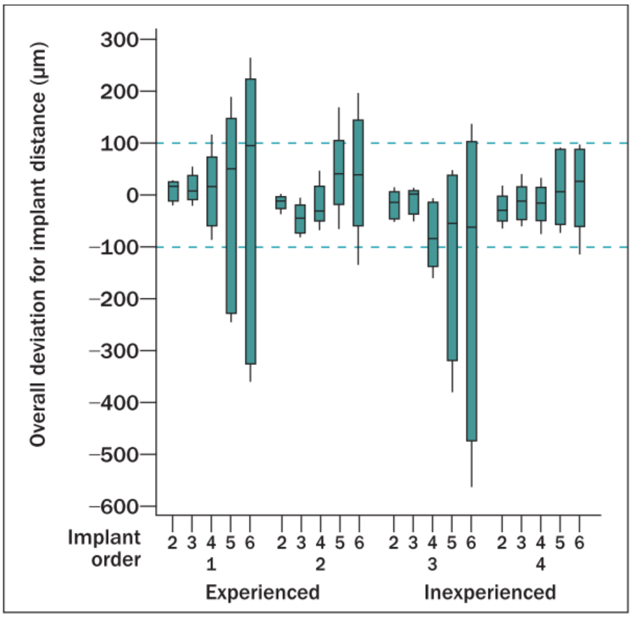

Figure 14: Deviation for implant distance (µm) in relation with the operators' experience.(18)

Huge discrepancies between the different operators appeared but not in the expected way. Both the experimented and unexperimented group managed to have an overall good accuracy result and a really bad one. This can help discarding the unexperienced-high discrepancies relationship. On the other hand, the fact that the operator can affect the results can't be discarded.

Resend C and cols published an article in 2020 focusing only over the influence of operators' experience. An "irrelevant" as said in the article 6 µm average of lower precision where measured when comparing the precision between experienced operator scans and unexperienced ones. Again, experience didn't prove to be an advantage for a better accuracy confirming our previous statement(26)

Operator×Scanner	Scanning Time (sec) (Mean)	Number of Images (Mean)
Medium experience and TRIOS 3	186.22 A	1720
High experience and TRIOS 3	189.88 A	2046
High experience and CEREC Omnicam	191.88 A	-
Medium experience and CEREC Omnicam	212.88 AB	-
Low experience and TRIOS 3	242.77 BC	2405
Low experience and CEREC Omnicam	260.66 C	-

Figure 15: table representing the average number of images taken by the IOS.(26)

Still in the same article, an advantage of the experienced group was highlighted thanks to the table from figure 15. the experienced operators tend to need less images to make a complete scan, reducing the risk of overlapping, reducing the total weight of the folder and they have a highly increased scanning speed.(26)

To close this section, A final comparison will be used, coming from an article written by Canulo L and cols where scans over plaster cast were performed, once again by an experienced group (more than two years of experience) and a non-experienced one.(17)

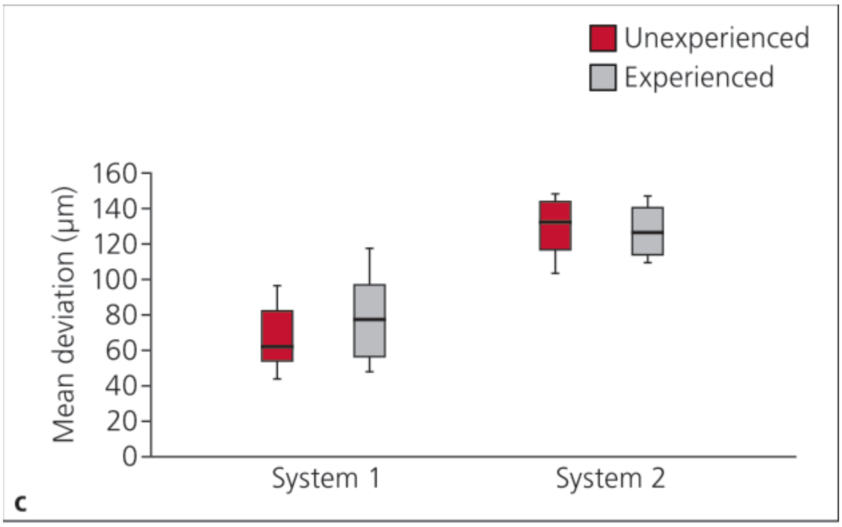

Figure 16: Chart of the mean deviation of 2 systems when used by different level of experience group.(17)

The same results can be observed on this chart from figure 16. The experience in itself doesn't constitute a major factor in order to reach good levels of accuracy when using an IOS device but it can help the operator to do it more efficiently.

4.2.2.3 Lighting and shade selection tool:

We have seen that reflected light could create unwanted artifact and disturb the digital workflow, so it might be necessary to make some research to understand if whether or not there is a more suitable ambient lighting level that could be used by the IOS operators when trying to achieve a high accuracy work. After determining it, we will also look at whether the shade selection tool can really help the operator to determine a good prosthesis shade.

Ambient lighting and its influence have been studied in 2018 by Arakida T and cols under controlled conditions where the only variant element was the lighting.(27) The studied lightning was registered threw two parameters both Kelvin (K) and Lux. Kelvin correspond to the light temperature and Lux is the illuminance level. Four kelvin settings were tested. 3900 K correspond to a yellow light, 4100 K to orange, 7500 K to white and 19000 K to blue

Three Lux levels were tested:

- 0 Lux, 500 Lux and 2500 Lux

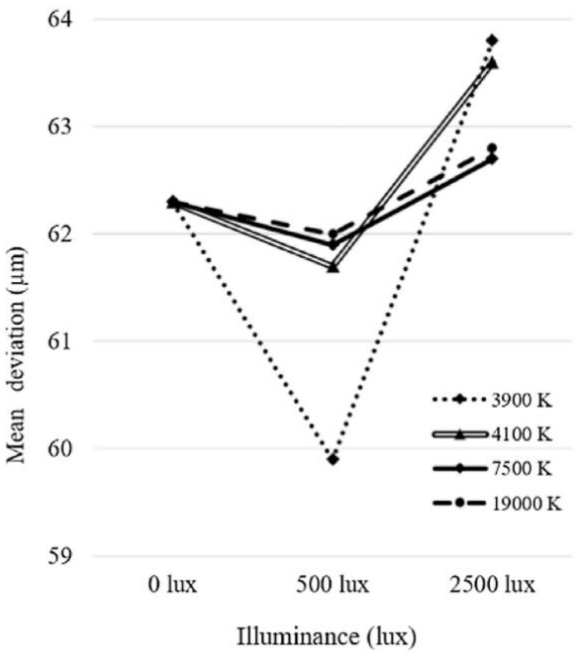

Figure 17: Graph of the mean deviation results correlating the tested illuminance and temperature.(27)

One particular lighting condition proved to have at least a mean discrepancy 2 µm inferior to the other ones. 3900 K at 500 Lux is the ideal correlation.

Although a 2 µm improve would be insufficient to justify a complete change of the clinic lighting, it is an ideal correlation as the average light levels of a clinic are around those values.(27) On the other hand, a 2500 Lux represented the average dental unit light so it is advisable to switch this one off before using any of the scanning devices.

Talking about ideal lighting conditions, something that had to be performed in good ones was having to make the crucial shade selection in order to have a harmonious final prosthetic result. Nowadays some Intraoral scanners integrate this function, we will have a look to it in order to know if it is more or less accurate than the conventional method and if the operator can affect the truthiness of the software.

A study conducted by Yilmaz B and cols was published in 2019 where the IOS software is compared against 25 observers doing a conventional visual shade selection, using a Vita® 3D master shade guide. The reference group is done with a spectrophotometer (VES) considered as the gold standard so far (All registration were made under the same controlled light conditions).(28)

TABLE 1 Tooth shade measurement results of VES taken from the cervical, middle, and incisal thirds of the teeth of the patients under 6500 and 4000 K lights

	Patient 1		Patient 2		Patient 3		Patient 4		Patient 5	
	6500 K	4000 K	6500 K	4000 K	6500 K	4000 K	6500 K	4000 K	6500 K	4000 K
Cervical	2L1.5	2L1.5	1M1	1M1	2M1	2M1	2R1.5	2R1.5	2M1	2M1
Middle	2M1	2M1	1M1	1M1	2M1	2M1	2L1.5	2L1.5	2M1	2M1
İncisal	2M1	2M1	1M1	1M1	2M1	2M1	2M1	2M1	1M1	1M1

TABLE 2 Tooth shade measurement results of T-3S taken from the cervical, middle, and incisal thirds of the teeth of the patients under 6500 and 4000 K lights

	Patient 1		Patient 2		Patient 3		Patient 4		Patient 5	
	6500 K	4000 K	6500 K	4000 K	6500 K	4000 K	6500 K	4000 K	6500 K	4000 K
Cervical	1M2	1M2	1M2	1M2	1M2	1M2	2M3	2M3	1M2	1M2
Middle	1M2	1M2	1M2	1M2	1M2	1M2	1M2	1M2	1M2	1M2
İncisal	1M1	1M1	2L1.5	2L1.5	2L1.5	2L1.5	2L1.5	2L1,5	2M1	2M1

TABLE 3 Commonly determined shades and their frequency (%) in visual shade selection results of all observers under two lighting conditions

	Patient 1		Patient 2		Patient 3		Patient 4		Patient 5	
	6500 K	4000 K	6500 K	4000 K	6500 K	4000 K	6500 K	4000 K	6500 K	4000 K
Cervical	2M2 (32%)	2L1.5 (24%) 2M2 (24%) 2R1.5 (24%)	1M2 (28%) 2M1 (28%)	1M2 (28%) 2M1 (28%)	2M2 (32%)	2M2 (36%)	2M2 (48%)	2M2 (24%)	2M1 (40%)	2M1 (36%)
Middle	2M1 (36%)	2M1 (32%) 2M2 (32%)	2M1 (44%)	2M1 (48%)	2M1 (44%)	2M1 (40%)	2L1.5 (24%)	1M2 (32%)	1M1 (44%)	1M1 (56%)
İncisal	2M1 (44%)	2M1 (48%)	2M1 (44%)	1M1 (32%) 2M1 (32%)	2M1 (36%)	1M1 (24%)	2M1 (28%)	2L1.5 (24%)	1M1 (64%)	1M1 (84%)

Figure 18: Table of the results from Yilmaz B. study.(28)

The outcomes of this study are that the IOS shade selection isn't affected by the light conditions, neither by the operator. Line by line it kept consistent throughout its measures. The IOS came out to be at least equal or even better than the visual shade selection done by the observers. In a clinical practice, it could be used as a spectrophotometer replacement.(28)

This integrated function turned out to be a really accurate and is a real function to help the dentist to achieve a high-quality prosthetic or esthetic result.

4.2.2.4 Scanning aids:

In this final section of our discussion, we will investigate over the "scanning aids" that can be applied by the operator over the scanned object. As mentioned previously in the introduction, depending on the IOS brand and model, they are mandatory, but in the case that it isn't required, the operator can feel free to use it or not. We will see if whether or not they can affect the accuracy or not.

Determining whether it is advisable or not to apply a scanning aid in order to reach a higher accuracy result has proven to be fairly difficult, as not all the authors do agree on the subject. Authors like Nedelcu R and cols when comparing the accuracy of 3 IOS said that he could not point out any difference in between the coating and non-coating mechanisms.(19) This would pull the scale toward the non-coating method as no time should be wasted by having more steps if there are no benefits.

On the other hand, Prudente M and cols made a complete study over the powder application as a scanning aid, and a different conclusion from the previous one was pulled out from it.(11) First of all, multiple IOS brand and model were used and not all of them reacted equally to the powder application. (figure 19)

Table 2. Mean ±SD vertical, horizontal, and volumetric 3D internal fitting values without adjustments (n=10)

Group	Vertical (μm)	Coefficient of Variation (%)	Percentage <75 μm	Horizontal (μm)	Volumetric 3D Internal Fit (mm^3)
B	29.5 ±13.2^A	44.7	89.3	56.2 ±21.5^A	9.4 ±1.3^A
O	149.4 ±64.4^B	43.0	31.0	77.5 ±11.8^B	11.8 ±2.1^B
OP	33.0 ±8.3^A	25.0	92.0	91.4 ±19.4^B	9.6 ±0.9^A

B, Bluecam crown; O, Omnicam crown; OP, Omnicam crown with powder. Values with same superscript letters were not significantly different in columns, based on 1-way analysis of variance test.

Table 3. Mean data of internal fit values (μm) for buccolingual and mesiodistal dimensions (n=10)

	M1		M2		M3		M4		M5		M6	
Group	BL	MD	BL	MD	BL	MD	BL	MD	BL	MD	BL	MD
B	83.0	49.7	29.9	85.7	129.7	230.9	132.4	161.6	16.0	74.1	69.7	55.1
BA	119.1	29.0	46.9	57.6	64.7	137.1	183.9	196.3	45.4	124.1	49.4	98.4
O	168.3	143.0	28.8	28.2	51.7	87.9	276.9	105.1	0	21.6	220.5	189.7
OA	217.9	100.8	76.9	65.1	55.6	111.5	256.2	95.9	26.2	55.8	128.8	171.0
OP	132.6	100.6	35.1	72.9	119.8	156.6	171.7	134.1	16.0	39.9	77.3	115.0

B, Bluecam crown; BA, Bluecam crown with adjustments; BL, buccolingual; M1-M6, 6 points used to measure internal misfit; MD, mesiodistal; O, Omnicam crown; OA, Omnicam crown with adjustments; OP, Omnicam crown with powder.

Table 4. Bluecam mean ±SD vertical, horizontal, and volumetric 3D internal fit values before and after adjustments (n=10)

Group	Vertical (μm)	Coefficient of Variation (%)	Percentage <75 μm	Horizontal (μm)	Volumetric 3D Internal Fit (mm^3)
B	29.5 ±13.2^A	44.7	89.3	56.2 ±21.5^A	9.4 ±1.3^A
BA	26.9 ±7.7^A	28.0	92.7	85.8 ±44.4^B	10.7 ±1.0^B

B, Bluecam crown; BA, Bluecam crown with adjustments. Values with same superscript letter not significantly different on columns based on paired *t* test (P>.05).

Table 5. Mean ±SD Omnicam values for vertical, horizontal, and volumetric 3D internal fit before and after adjustments (n=10)

Group	Vertical (μm)	Coefficient of Variation (%)	Percentage <75 μm	Horizontal (μm)	Volumetric 3D Internal Fit (mm^3)
O	149.4 ±64.4^A	43.0	31	77.5 ±11.8^A	11.8±2.1^A
OA	49.4 ±12.7^B	25.7	73.5	102.5 ±16.2^B	11.0±1.3^A

O, Omnicam crown; OA, Omnicam crown with adjustments. Values with same superscript letter not significantly different on columns based on paired *t* test (P>.05).

Figure 19: Table of results comparing IOS accuracy when TiO_2 powder was used.(11)

Marginal discrepancies values were clearly affected by the presence of powder. We can either see an improvement in terms of accuracy in some brand and models, but in some others, we can get detrimental values. This also depend on the different surfaces of the preparation. Looking at the Omnicam® for example, the vertical fit got better, but the overall 3D internal fit got worst. No particular benefit can be pulled out from these results. (11)

Whether or not there should be a scanning aid application, it is free to the operator's choice, knowing the previous results it got. Multiple aids are disponible on the market, particularly the powder ones and the liquid application ones so it sounds legitimate to look for potential differences in between those two.

It is exactly the aim of the design of Oh H and cols study.(29) Two powder sprays were compared to a liquid painting scanning aid. In all of them, the main component was TiO2. Different types of restoration were taken into account like: inlay, onlay and bridges.

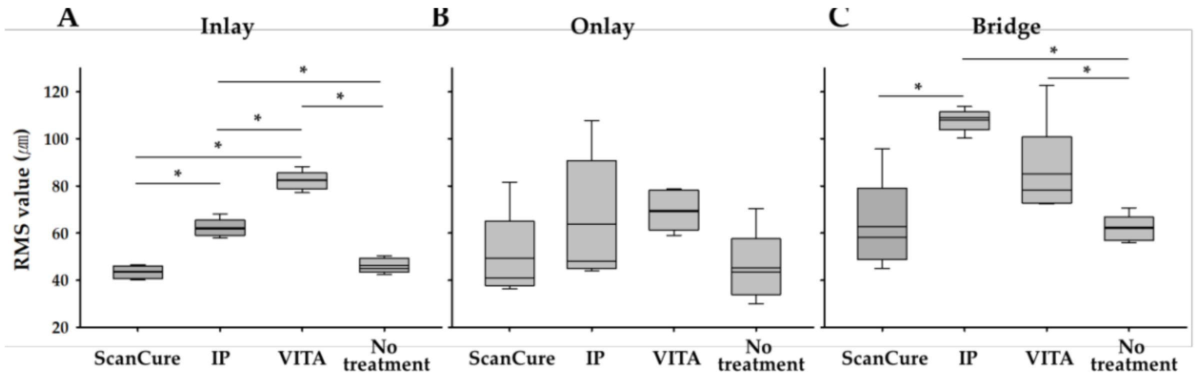

Figure 20: Chart of the results comparing the discrepancies when using the application of different types of scanning aid in different clinical conditions.(29)

The results are clear. Whatever the chosen type of restauration, the liquid scan aid (ScanCure® in this case) always gives more accurate results than the classical powder spray ones. But when compared with the non-application of scanning aid group, the discrepancies were close to none. The improved results of the liquid over the powder are due to the fact that the operator can perfectly control the thickness and extend of the material thanks to a brush.(29)

The application of a scanning aid doesn't present itself as a mandatory tool when trying to reach for the most accurate result. In the case the operator feels like it is needed, the "liquid painting" form can be recommended over the others

5. Conclusion:

1- The general accuracy of intraoral scanners is highly satisfying, it can be indicated in all sorts of restorations as soon as body fluids can be under control, that the scanned arch length is reasonable, and it is advisable to use the manufacturer's software.

2- The scanning protocol proved to be of low importance as in the majority of the cases. However, as some models could be affected by it, we could recommend using the corresponding protocol given by the manufacturer.

3- Operator's experience proved to affect only the time needed to perform a scan and the file size. Apart from that, no particular discrepancies were encountered. It turned out to be a negligeable factor.

6. **Responsibility:**

As far as the economic sustainability is concerned, for this paper, it is subjective to the reader. If we consider the IOS as a direct concurrent to the conventional impression methods, it is clear that switching to a full digital system like this subject could encourage to do, correspond to an important investment, both when buying and maintaining it. However, once the investment is made, we could find it multiple advantages that could enhance the clinic's finances such as the higher working speed with a 100% digital workflow, the long-term economies made over the laboratories expanses and the publicity made thanks to these machines. However, working with this type of material can probably be an interesting long-term investment. Otherwise, the conventional tray impressions are cheaper to use. This overall aspect could even be the subject of a full study.

For the environmental sustainability, it is true that working digitally, directly in the office can be beneficial as close to zero consumables are used, thus, leaving nothing to waste. This high-end material can potentially be recycled in its majority as more and more companies tend to be eco-friendly.

Finally, the social sustainability aspect, which is the most accurate one, particularly during the period in which this paper is written. Once again, a digital workflow in an epidemic like COVID-19 is favorable as cross contamination is limited because exchanges between dental technician, the dentist and the patients are reduced or inexistant. Machine materials can all be disinfected, and some pieces of the IOS can even be sterilized. The workplace is then made safer.

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Review

A review of dental CAD/CAM: current status and future perspectives from 20 years of experience

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In this article, we review the recent history of the development of dental CAD/CAM systems for the fabrication of crowns and fixed partial dentures (FPDs), based on our 20 years of experience in this field. The current status of commercial dental CAD/CAM systems developed around the world is evaluated, with particular focus on the field of ceramic crowns and FPDs. Finally, we discuss the future perspectives applicable to dental CAD/CAM. The use of dental CAD/CAM systems is promising not only in the field of crowns and FPDs but also in other fields of dentistry, even if the contribution is presently limited. CAD/CAM technology will contribute to patients' health and QOL in the aging society.

Key words: CAD/CAM, Crowns and fixed partial dentures, Digitizing, Network, Zirconia

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INTRODUCTION

In dentistry, we have a long history of contributing to the needs of patients by offering dental restorative and prosthetic devices such as inlays, onlays, crowns, fixed partial dentures (FPDs), and removable dentures, to recover patients' oral function and maintain their health. In contrast with other ordinal industrial products, such dental devices were originally tailor-made to the patient's individual condition. During the 20th century, both dental materials and dental technologies for the fabrication of dental devices progressed remarkably. The lost-wax precision casting of gold alloys, dough modeling and curing of acrylic resins, and powder sintering of dental porcelains were originally developed for dentistry and are well established as conventional dental laboratory technologies. There is no doubt that high quality dental devices can be routinely fabricated through the collaboration of dentists and dental technicians. Nevertheless, dental laboratory work still remains to be labor-intensive and experience-dependent.

Owing to the increased demand for safe and esthetically pleasing dental materials, new high-strength ceramic materials have been recently introduced as materials for dental devices[1, 2]. Since these materials have proved to be inimical to conventional dental processing technology, new sophisticated processing technologies and systems have been anticipated for introduction into dentistry. One solution to this is the introduction of computer-aided design and computer-aided manufacturing (CAD/CAM) technology.

In relation to the rapid progress being made in computer-assisted processing technology in various industries since the 1970s, research and development of dental CAD/CAM systems has been actively pursued worldwide since the 1980s, including in Japanese academies[3-13]. Recently, commercial dental CAD/CAM systems have been introduced for specific fields such as all-ceramic restorations. In this article, we describe the recent history of the development of dental CAD/CAM systems for the fabrication of crowns and FPDs, based on our 20 years of experience in this field. We also summarize the current state of commercial dental CAD/CAM systems that have been developed around the world, with particular focus on the field of ceramic crowns and FPDs. Finally, we discuss the future perspectives applicable to dental CAD/CAM.

A BRIEF HISTORY OF DENTAL CAD/CAM

When we started research and development in the 1980s, the design and processing of dental devices using CAD/CAM technology was generally believed to be simpler and easier than for industrial products. However, in reality, dental CAD/CAM is neither simple nor easy for the following reasons:

1) Total cost, operation time, and manipulation of the systems for processing dental devices using CAD/CAM technology should be at the levels found in conventional systems, or be superior, to replace the conventional individual tailor-made restorations and ensure that new systems are practical in daily laboratory work and clinical practice.
2) Morphology of the abutment teeth, related adjacent teeth, and related opponent teeth

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Digitization of simulated clinical dental impressions: Virtual three-dimensional analysis of exactness

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ABSTRACT

Objectives. To compare the exactness of simulated clinical impressions and stone replicas of crown preparations, using digitization and virtual three-dimensional analysis.
Methods. Three master dies (mandibular incisor, canine and molar) were prepared for full crowns, mounted in full dental arches in a plane line articulator. Eight impressions were taken using an experimental monophase vinyl polysiloxane-based material. Stone replicas were poured in type IV stone (Vel-Mix Stone; Kerr). The master dies and the stone replicas were digitized in a touch-probe scanner (Procera® Forte; Nobel Biocare AB) and the impressions in a laser scanner (D250, 3Shape A/S), to create virtual models. The resulting point-clouds from the digitization of the master dies were used as CAD-Reference-Models (CRM). Discrepancies between the points in the pointclouds and the corresponding CRM were measured by a matching-software (CopyCAD 6.504 SP2; Delcam Plc). The distribution of the discrepancies was analyzed and depicted on color-difference maps.
Results. The discrepancies of the digitized impressions and the stone replicas compared to the CRM were of similar size with a mean ± SD within 40 μm, with the exception of two of the digitized molar impressions. The precision of the digitized impressions and stone replicas did not differ significantly ($F = 4.2$; $p = 0.053$). However, the shape affected the digitization ($F = 5.4$; $p = 0.013$) and the interaction effect of shape and digitization source (impression or stone replica) was pronounced ($F = 28$; $p < 0.0001$). The reliability was high for both digitization methods, evaluated by repeated digitizations.
Significance. The exactness of the digitized impressions varied with shape. Both impressions and stone replicas can be digitized repeatedly with a high reliability.

1. Introduction

The quality of dental prosthetic restorations has improved significantly since the introduction of a standardized production process. CAD/CAM (Computer aided design/Computer aided manufacturing) technology has made it possible to utilize interesting new prosthetic materials such as the high performance ceramics.

Three-dimensional surface imaging is rapidly becoming the method of choice for acquiring input information for the fabrication of fixed prosthetic restorations. In order to transform the prepared tooth into a virtual preparation, several

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Marginal adaptation of three different zirconium dioxide three-unit fixed dental prostheses

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Statement of problem. Marginal adaptation is important for the long-term success of dental restorations. Data on the marginal discrepancy of zirconia-based fixed dental prostheses made with different computer-aided design/computer-aided manufacturing technology is needed.

Purpose. The purpose of this study was to evaluate the marginal adaptation of different zirconia 3-unit fixed dental prostheses at different fabrication stages and after artificial aging.

Material and methods. Twenty-four zirconia 3-unit fixed dental prostheses (DCS, Procera, and VITA YZ-Cerec; n=8) were fabricated using different manufacturing systems and conventionally cemented with glass ionomer cement on human teeth. Each group was aged in a masticatory simulator with thermal cycling. The marginal gaps were examined on epoxy replicas for frameworks and for restorations before and after cementation, and after masticatory simulation, at x250 magnification. Marginal adaptation was assessed using geometric means of the marginal gap values with 95% confidence intervals. Differences between the manufacturing systems and the effect of artificial aging were tested using repeated-measures ANOVA and post hoc paired and unpaired *t* tests with Bonferroni-Holm correction (α=.05).

Results. The geometric mean (95% confidence limits) marginal gap values (µm) for frameworks and for restorations before cementation, after cementation, and after masticatory simulation were, respectively: DCS: 86 (80-93), 86 (83-90), 86 (78-94), and 84 (79-90); Procera: 82 (74-89), 89 (81-97), 89 (84-95), and 88 (82-94); and VITA YZ-Cerec: 64 (57-72), 67 (61-77), 76 (71-82), and 78 (76-80). The repeated-measures ANOVA showed significant group and stage effects (P<.05). Group VITA YZ-Cerec showed significantly smaller marginal gap values than groups DCS and Procera at framework (P<.05) and before-cementation (P<.05) stages. The VITA YZ-Cerec group showed significantly smaller marginal gap values than the Procera group after cementation (P<.05). The marginal gap values between different stages were not significantly different for all groups (P>.05).

Conclusions. The marginal accuracy of zirconia fixed dental prostheses is influenced by manufacturing technique. (J Prosthet Dent 2009;101:239-247)

Clinical Implications

All 3 types of CAD/CAM all-ceramic fixed dental prostheses tested in the present study demonstrate marginal accuracy that is considered acceptable for clinical application (<100 µm).

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Displacement of scan body during screw tightening: A comparative *in vitro* study

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PURPOSE. The purpose of this study was to evaluate the occurrence of displacement while tightening the screw of scan bodies, which were compared according to the material type. **MATERIALS AND METHODS.** Three types of scan bodies whose base regions were made up of polyether ether ketone (PEEK) material [Straumann Group, Dentium Group, and Myfit (PEEK) Group] and another scan body whose base region was made up of titanium material [Myfit (Metal) Group] were used (15 per group). The reference model was fabricated by aligning the scan body library on the central axis of the implant, and moving this position by the resin model. The screws of the scan bodies were tightened to the implant fixture with torques of 5 Ncm, 10 Ncm, and a hand tightening torque. After the application of the torque, the scan bodies were scanned using a laboratory scanner. To evaluate the vertical, horizontal, and 3-dimensional (3D) displacements, a 3D inspection software program was used. To examine the difference among groups, one-way analysis of variance and Tukey's HSD post hoc test were used (α=.05). **RESULTS.** There were significant differences in 3D, vertical, and horizontal displacements among the different types of scan bodies (P<.001). There was a significantly lower displacement in the Straumann group than in the Myfit (PEEK) and Dentium groups (P<.05). **CONCLUSION.** The horizontal displacement in all groups was less than 10 µm. With the hand tightening torque, a high vertical displacement of over 100 µm occurred in PEEK scan bodies (Myfit and Dentium). Therefore, it is recommended to apply a tightening torque of 5 Ncm instead of a hand tightening torque. ***[J Adv Prosthodont 2020;12:307-15]***

KEYWORDS: Dental implant; Scan body; Tightening torque; Displacement; Polyether ether ketone (PEEK)

INTRODUCTION

With the development of the dental computer-aided design and computer-aided manufacturing (CAD/CAM) system, many studies have verified the stability of the CAD/CAM system. This system has materialized the technique of digital scanning, which substitutes the conventional impression technique.[1-8] Previous studies have reported that the digital impression is clinically more accurate than the conventional impression.[9,10] The digital scan method tightens the screw of the scan body to the implant in the patient's oral cavity and a virtual model is produced when scanning is conducted using an intraoral scanner.[6] On the acquired virtual model, the position of the actual implant is estimated by the position of the scan body.[6] It was reported that the digital scan method reduces error related to the operator's skill and rubber material while increasing the patients' satisfaction as compared to the conventional impression technique.[8] Previous studies have reported that implant restorations produced using a digital workflow had a better passive fit than ones

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CLINICAL ORAL IMPLANTS RESEARCH

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In vitro precision of fit of computer-aided designed and computer-aided manufactured titanium screw-retained fixed dental prostheses before and after ceramic veneering

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Key words: computer-aided designed and computer-aided manufactured, fixed dental prosthesis, implant framework fit, implant-supported, passive fit, porcelain firing, precision of fit

Abstract

Objective: To compare the precision of fit of full-arch implant-supported screw-retained computer-aided designed and computer-aided manufactured (CAD/CAM) titanium-fixed dental prostheses (FDP) before and after veneering. The null-hypothesis was that there is no difference in vertical microgap values between pure titanium frameworks and FDPs after porcelain firing.

Materials and methods: Five CAD/CAM titanium grade IV frameworks for a screw-retained 10-unit implant-supported reconstruction on six implants (FDI tooth positions 15, 13, 11, 21, 23, 25) were fabricated after digitizing the implant platforms and the cuspid-supporting framework resin pattern with a laser scanner (CARES® Scan CS2; Institut Straumann AG, Basel, Switzerland). A bonder, an opaquer, three layers of porcelain, and one layer of glaze were applied (Vita Titankeramik) and fired according to the manufacturer's preheating and fire cycle instructions at 400–800°C. The one-screw test (implant 25 screw-retained) was applied before and after veneering of the FDPs to assess the vertical microgap between implant and framework platform with a scanning electron microscope. The mean microgap was calculated from interproximal and buccal values. Statistical comparison was performed with non-parametric tests.

Results: All vertical microgaps were clinically acceptable with values <90 μm. No statistically significant pairwise difference ($P = 0.98$) was observed between the relative effects of vertical microgap of unveneered (median 19 μm; 95% CI 13–35 μm) and veneered FDPs (20 μm; 13–31 μm), providing support for the null-hypothesis. Analysis within the groups showed significantly different values between the five implants of the FDPs before ($P = 0.044$) and after veneering ($P = 0.020$), while a monotonous trend of increasing values from implant 23 (closest position to screw-retained implant 25) to 15 (most distant implant) could not be observed ($P = 0.169$, $P = 0.270$).

Conclusions: Full-arch CAD/CAM titanium screw-retained frameworks have a high accuracy. Porcelain firing procedure had no impact on the precision of fit of the final FDPs. All implant microgap measurements of each FDP showed clinically acceptable vertical misfit values before and after veneering. Thus, the results do not only show accurate performance of the milling and firing but show also a reproducible scanning and designing process.

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Precise framework fit is considered an essential factor for the long-term success of a fixed dental prosthesis (FDP), although perfect accuracy is only achievable in theory (Sahin & Cehreli 2001). While consensus among dentists exists that a marginal misfit of less than 120 μm is clinically acceptable for an implant- or toothborne fixed dental prosthesis (FDP), this threshold is not supported by scientific evidence (McLean & von Fraunhofer 1971; Belser et al. 1985; Kydd et al. 1996; Beuer et al. 2009). The impact of the marginal gap size of an ill-fitting clinically unacceptable FDP on the peri-implant tissues and the restoration is discussed controversially. Bacterial invasion into the microgap may cause mucositis and peri-implantitis with progressive bone loss (Aloise et al. 2010; Teixeira et al. 2011). While few short-term biological complications have been reported for implants that support one-piece, full-arch restorations, long-term effects are unknown (Hedkvist et al. 2004). From a clinical point of view, however, it can be assumed that

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RESEARCH AND EDUCATION

Evaluation of the accuracy of 7 digital scanners: An in vitro analysis based on 3-dimensional comparisons

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ABSTRACT

Statement of problem. As digital impressions become more common and more digital impression systems are released onto the market, it is essential to systematically and objectively evaluate their accuracy.

Purpose. The purpose of this in vitro study was to evaluate and compare the trueness and precision of 6 intraoral scanners and 1 laboratory scanner in both sextant and complete-arch scenarios. Furthermore, time of scanning was evaluated and correlated with trueness and precision.

Material and methods. A custom complete-arch model was fabricated with a refractive index similar to that of tooth structure. Seven digital impression systems were used to scan the custom model for both posterior sextant and complete arch scenarios. Analysis was performed using 3-dimensional metrology software to measure discrepancies between the master model and experimental casts.

Results. Of the intraoral scanners, the Planscan was found to have the best trueness and precision while the 3Shape Trios was found to have the poorest for sextant scanning ($P<.001$). The order of trueness for complete arch scanning was as follows: 3Shape D800 >iTero >3Shape TRIOS 3 >Carestream 3500 >Planscan >CEREC Omnicam >CEREC Bluecam. The order of precision for complete-arch scanning was as follows: CS3500 >iTero >3Shape D800 >3Shape TRIOS 3 >CEREC Omnicam >Planscan >CEREC Bluecam. For the secondary outcome evaluating the effect time has on trueness and precision, the complete- arch scan time was highly correlated with both trueness (r=0.771) and precision (r=0.771).

Conclusions. For sextant scanning, the Planscan was found to be the most precise and true scanner. For complete-arch scanning, the 3Shape Trios was found to have the best balance of speed and accuracy. (J Prosthet Dent 2017;118:36-42)

Intraoral digital impression making has evolved beyond single tooth preparations and sextant scanning to include the ability to record complete arches. Intraoral digital scanners allow the dentist to capture the surface of the teeth, implant scanbodies, and soft tissues in 3 dimensions, enabling instant evaluation of the digital cast and near instant communication to the laboratory, 3-dimensional (3D) printer, or chairside milling unit. Similarly, computer-aided design and computer-aided manufacturing (CAD-CAM) has revolutionized the way dentistry is practiced and has become integrated into patient care.[1,2] Recent advances in chairside and laboratory digital technology have cultivated an enhanced environment for the widespread use of digital dentistry.[1,2]

Two events that have increased the acceptance of digital technology are the emergence of newer and more user friendly intraoral digital scanners and the adoption of digital technology into dental school curricula.[3] Deficiencies with elastomeric impression materials and techniques have been documented to support the need for new and better impression techniques.[4-8] Commonly reported weaknesses of elastomeric impression materials

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sensors

MDPI

Article

Accuracy of CAD/CAM Digital Impressions with Different Intraoral Scanner Parameters

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Abstract: The advancement of intraoral scanners has allowed for more efficient workflow in the dental clinical setting. However, limited data exist regarding the accuracy of the digital impressions produced with various scanner settings and scanning approaches. The purpose of this in vitro study was to compare the accuracy of digital impressions at the crown preparation margin using different scanning resolutions of a specific intraoral scanner system. An all-ceramic crown preparation of a mandibular first molar was constructed in a typodont, and a scan (n = 3) was created with an industrial-grade laboratory scanner (3Shape D2000) as the control. Digital impressions were obtained with an intraoral scanner (3Shape TRIOS 3) under three settings—high resolution (HR), standard resolution (SR), and combined resolution (SHR). Comparative 3D analysis of scans was performed with Geomagic Control X software to measure the discrepancy between intraoral scans and the control scan along the preparation finish line. The scan time and number of images captured per scan were recorded. Statistical analysis was performed by one-way ANOVA, two-way repeated measures ANOVA, Pearson's correlation, and Dunnett's T3 test ($\alpha = 0.05$). Significant differences were observed for scan time and for number of images captured among scan resolution settings ($\alpha < 0.05$). The scan time for the SR group was, on average, 34.2 s less than the SHR group and 46.5 s less than the HR group. For discrepancy on the finish line, no significant differences were observed among scanning resolutions (HR: 31.5 ± 5.5 μm, SHR: 33.2 ± 3.7 μm, SR: 33.6 ± 3.1 μm). Significant differences in discrepancy were observed among tooth surfaces, with the distal surface showing the highest discrepancies. In conclusion, the resolution of the intra-oral scanner is primarily defined by the system hardware and optimized for default scans. A software high-resolution mode that obtains more data over a longer time may not necessarily benefit the scan accuracy, while the tooth preparation and surface parameters do affect the accuracy.

Keywords: digital impression; CAD/CAM; accuracy; intraoral scanner; high resolution

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1. Introduction

Computer-aided design and computer-aided manufacturing (CAD/CAM) technology has drastically changed the face of dentistry since it was introduced to the field in the 1980s [1]. In the early stages of the application of CAD/CAM to dentistry, desktop scanners were used in dental laboratories to digitize gypsum models before the milling and manufacturing of dental prosthetics [2]. Most recently, the advancement of chairside CAD/CAM systems has provided a more efficient digital workflow in the clinical setting [3]. In the last two decades, many commercially available intraoral scanners (IOS) have been developed [4], and both in vivo and in vitro studies have examined the accuracy and precision of various intraoral scanners compared to conventional impression materials and techniques [5]. The use of intraoral scanners as an alternative to conventional impression reduces patient discomfort, is more environmentally friendly, and is easier for clinicians to manipulate without the risk of

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Evaluation of the Precision of Different Intraoral Scanner-Computer Aided Design (CAD) Software Combinations in Digital Dentistry

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Study Design A
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Manuscript Preparation E
Literature Search F
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Background: The aim of this study was to evaluate the precision of correlation between intraoral scanners and computer aided design (CAD) software programs used during scanning and designing phases of digital dentistry. In the present study, CAD software programs that accept data in Standard Tessellation Language (STL) and proprietary format have been evaluated and data loss has been examined in the scanned data.

Material/Methods: A single unit crown preparation was conducted for maxillary right first molar on a fully dentulous model. The prepared tooth was scanned with a high precision industrial scanner (ATOS Core 80) and the reference digital model was obtained. The dental model was further scanned 10 times using 3 different intraoral scanners (CEREC Omnicam AC, TRIOS 3 Color Pod, and Aadva IOS 100). The data obtained from the reference scanner and intraoral scanners were transferred to different CAD programs (CEREC inLab, TRIOS Design Studio, Exocad) and digital crowns were designed for each scanned data-CAD combination. After that, the data losses that occurred between these transfers were evaluated by superimposition technique in a special software (VR Mesh v7.5) (α=0.05).

Results: Among the all combinations of scanner and software, Omnicam AC-InLab was determined to be the most precise combination through the full digital workflow since the Omnicam AC-Exocad combination showed the highest deviations.

Conclusions: Within the limitations of this *in vitro* study, it was determined that the combinations of scanners and associated CAD programs yielded more accurate results, and data loss was revealed when the scanned data converted from the proprietary format to the STL format.

MeSH Keywords: **Analog-Digital Conversion • Computer-Aided Design • Dental Clinics**

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RESEARCH ARTICLE

Accuracy of four digital scanners according to scanning strategy in complete-arch impressions

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Abstract

Statement of problem

Although there are specific and general digital scanning guidelines depending on the system used, it is important to have the necessary flexibility in the acquisition of three-dimensional (3D) images to adapt to any clinical situation without affecting accuracy.

Purpose

The purpose of this in vitro study was to identify and compare the scanning strategy with the greatest accuracy, in terms of trueness and precision, of four intraoral scanners in the impression of a complete dental arch.

Material and methods

Four digital scanners were evaluated with a 3D measuring software, using a highly accurate reference model obtained from an industrial scanner as a comparator. Four scanning strategies were applied 10 times on a complete maxillary arch cast inside a black methacrylate box. The data were statistically analyzed using one-way analysis of variance (ANOVA) and post hoc comparisons with Tamhane T2 test.

Results

The trueness of the Trios and iTero system showed better results with strategy "D," Omnicam with strategy "B," and True Definition with strategy "C". In terms of precision, both iTero and True Definition showed better results with strategy "D", while Trios showed best results with strategy "A" and Omnicam with strategy "B". There were significant differences between the scanning strategies ($p<0.05$) with the iTero scanner, but not with the other scanners ($p>0.05$).

Conclusions

The digital impression systems used in the experiment provided sufficient flexibility for the acquisition of 3D images without this affecting the accuracy of the scanner.

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Review

Advancements in CAD/CAM technology: Options for practical implementation

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ABSTRACT

Purpose: The purpose of this review is to present a comprehensive review of the current published literature investigating the various methods and techniques for scanning, designing, and fabrication of CAD/CAM generated restorations along with detailing the new classifications of CAD/CAM technology.
Study selection: I performed a review of a PubMed using the following search terms "CAD/CAM, 3D printing, scanner, digital impression, and zirconia". The articles were screened for further relevant investigations. The search was limited to articles written in English, published from 2001 to 2015. In addition, a manual search was also conducted through articles and reference lists retrieved from the electronic search and peer-reviewed journals.
Results: CAD/CAM technology has advantages including digital impressions and models, and use of virtual articulators. However, the implementation of this technology is still considered expensive and requires highly trained personnel. Currently, the design software has more applications including complete dentures and removable partial denture frameworks. The accuracy of restoration fabrication can be best attained with 5 axes milling units. The 3D printing technology has been incorporated into dentistry, but does not include ceramics and is limited to polymers. In the future, optical impressions will be replaced with ultrasound impressions using ultrasonic waves, which have the capability to penetrate the gingiva non-invasively without retraction cords and not be affected by fluids.
Conclusion: The coming trend for most practitioners will be the use of an acquisition camera attached to a computer with the appropriate software and the capability of forwarding the image to the laboratory.

Contents

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RESEARCH AND EDUCATION

Influence of scanner, powder application, and adjustments on CAD-CAM crown misfit

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ABSTRACT

Statement of problem. The manufacturers of computer-aided design and computer-aided manufacturing (CAD-CAM) systems emphasize that new technologies can improve the marginal fit of dental crowns. However, data supporting this claim are limited.

Purpose. The purpose of this in vitro study was to investigate the differences among the following fabrication methods on the marginal discrepancy of dental crowns: intraoral optical scanners, powder application, and adjustments of intaglio surface.

Material and methods. A single human premolar was fixed on a typodont and prepared to receive crowns prepared by the CEREC CAD-CAM system. Three fabrication techniques were used: digital scans using the CEREC Bluecam scanner with titanium dioxide powder (TDP), digital scans using the CEREC Omnicam scanner without TDP, and digital scans using the Omnicam scanner with TDP. Five experimental groups (n=10) were designated: Bluecam (group B), Bluecam with adjustments (group BA), Omnicam (group O), Omnicam with adjustments (group OA), and Omnicam with TDP (group OP). The specimens were scanned using microcomputed tomography to measure the vertical, horizontal, and internal fit and volumetric 3-dimensional (3D) internal fit values of each luting space. The paired *t* test was used to evaluate mean marginal fit change after adjustments within the same group. One-way analysis of variance and post hoc tests were used to compare groups B, O, and OP (α=.05).

Results. Mean vertical fit values ±standard deviations of group B=29.5 ±13.2 μm; BA=26.9 ±7.7 μm; O=149.4 ±64.4 μm; OA=49.4 ±12.7 μm; and OP=33.0 ±8.3 μm. Adjustments in the intaglio surface and TDP application statistically influenced the vertical fit of group O (*P*<.001). The percentage of vertical fit values <75 μm in group B=89.3%, BA=92.7%, O=31.0%, OA=73.5%, and OP=92.0%. Mean horizontal fit values for group B=56.2 ±21.5 μm; 85.8 ±44.4 μm for group BA; 77.5 ±11.8 μm for group O; 102.5 ±16.2 μm for group OA; and 91.4 ±19.4 μm for group OP. Results from group B were significantly different from those of the other test groups (*P*<.05). The percentages of horizontal misfit were 61.2% in group B; 73.5% in group BA; 88.1% in group O; 92.4% in group OA; and 85.0% in group OP. Volumetric 3D internal fit values in group B were 9.4 ±1.3 mm^3; 10.7 ±1.0 mm^3 in group BA; 11.8 ±2.1 mm^3 in group O; 11.0 ±1.3 mm^3 in group OA; and 9.6 ±0.9 mm^3 in group OP. The overall results from groups B and OP were better than those of group O, with regard to vertical misfit and volumetric 3D internal fit.

Conclusions. Different intraoral optical scanners, powder application, and internal adjustments influenced the marginal discrepancy of crowns. Crowns fabricated using the Omnicam system had significantly higher vertical discrepancy and volumetric 3D internal fit than those fabricated using the Bluecam scanner with TDP. Adjustments of the intaglio surface improved the vertical fit of crowns made using the Omnicam scanner; however, TDP application before Omnicam scanning improved the vertical fit as well as the volumetric 3D internal fit value of the luting space of crowns. (J Prosthet Dent 2018;119:377-83)

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CLINICAL RESEARCH

Accuracy of an intraoral digital scanner in tooth color determination

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ABSTRACT

Statement of problem. Whether intraoral digital scanners with an integrated shade-taking function can substitute for colorimeters, spectrophotometers, or the visual method to reduce working time is unclear.

Purpose. The purpose of this clinical study was to evaluate the accuracy of the measurement of tooth shade obtained with an intraoral digital scanner in vivo.

Material and methods. Shades of 120 maxillary anterior teeth were evaluated by using a SpectroShade spectrophotometer (SS) and a TRIOS 3 intraoral digital scanner (T3) on 20 participants. The matching of shade readings between the T3 and SS was used to estimate the accuracy of the T3. The percentage of readings when a difference between the shades obtained by both devices was visually perceptible ($\Delta E>3.7$) was calculated. Each of the 120 teeth was measured 5 times to assess repeatability.

Results. The accuracy of the T3 was 53.3% when the color was recorded as a Vita 3D-Master (VM) shade and 27.5% for the Vita Classical (VC) shade guide when the SS was taken as a reference. A visually perceptible color difference was found in 25% (VM) and 50.8% (VC) of situations when the shade was determined with the SS and 48.3% (VM) and 78.3% (VC) with the T3. Repeatability was 92% (VM) and 93.5% (VC) for the SS, and 90.33% (VM) and 87.17% (VC) for the T3.

Conclusions. The findings of this study revealed that the tooth color determined by the T3 does not exactly match that obtained by the SS that additional methods of measuring tooth color are recommended. The accuracy of the T3 was higher when the color was recorded as VM values rather than VC values. (J Prosthet Dent 2020;123:322-9)

Dental restorations should restore both function and esthetics. The desire to reproduce natural optical features in dental restorations and to meet the esthetic requirements of patients and dentists has led to the development of new restorative materials and instruments to determine and reproduce color.[1]

To identify the color of a tooth and to reproduce it in a dental restoration, commercial shade guides have been used. As an alternative, custom shade guides, from the restorative material itself, can be used.[2,3] One of the most popular commercial shade guides, the Vita Classical (VC) (Vita Zahnfabrik), is based on the color frequency of natural teeth. Competing shade guides (Noritake; Kuraray Noritake Dental Inc, Chromascop; Ivoclar Vivadent AG, Bioform; Dentsply Sirona) are also based on the same principle.[4] Another shade guide (Vita 3D-Master [VM]; Vita Zahnfabrik) is systematically arranged on the CIELCh color scale and has been reported to be more reliable.[5-11]

The calculation and measurement of the color difference (ΔE) between the 2 objects can be achieved by using the CIELab color scale, where the L axis refers to lightness (0=pure black, 100=pure white), the a axis refers to red-green chromaticity (+a=redness, −a=greenness), and the b axis shows yellow-blue chromaticity (+b=yellowness, −b=blueness). Under experimental conditions, $\Delta E>1$ can be seen by the human eye,[12] but the clinically visible color difference for a tooth has been reported to be when $\Delta E>3.7$.[13] When the tooth color is determined with shade guides, several shade tabs could be visually acceptable, because ΔE between the tabs and the tooth could be less than 3.7. It is also possible that all shade tabs are visually

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cancers

MDPI

Review

Role of Oral Bacteria in the Development of Oral Squamous Cell Carcinoma

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Simple Summary: Oral squamous cell cancer (OSCC) is still one of the major malignant tumors of the head and neck region with dissatisfactory survival rate. Recently, based on the high-throughput sequencing technology, OSCC has been verified a close relationship with oral bacteria. Our review aims to summarize these findings and raise our perspectives. We conclude that different oral bacteria show distinct alterations in the abundance and a certain combination of various bacteria might possibly be markers for OSCC diagnosis. Besides, oral bacteria such as *Porphyromonas gingivalis* and *Fusobacterium nucleatum* can participate in most cancer-promoting pathways to assist OSCC development. Therefore, oral bacteria may be a target to provide potential methods for early diagnosis and more effective treatments.

Abstract: Oral squamous cell carcinoma (OSCC) is an invasive epithelial neoplasm that is influenced by various risk factors, with a low survival rate and an increasing death rate. In the past few years, with the verification of the close relationship between different types of cancers and the microbiome, research has focused on the compositional changes of oral bacteria and their role in OSCC. Generally, oral bacteria can participate in OSCC development by promoting cell proliferation and angiogenesis, influencing normal apoptosis, facilitating invasion and metastasis, and assisting cancer stem cells. The study findings on the association between oral bacteria and OSCC may provide new insight into methods for early diagnosis and treatment development.

Keywords: oral squamous cell carcinoma; oral bacteria; inflammation

1. Introduction

Oral cancer is one of the major malignant tumors of the head and neck region, causing great mortality and morbidity [1,2]. According to the World Health Organization (WHO), there are around 657,000 new cases of oral cavity and pharyngeal cancers each year, with more than 330,000 deaths. Oral squamous cell carcinoma (OSCC), an invasive epithelial neoplasm with different degrees of differentiation, accounts for about 90% of oral cancer. It starts with the accumulation of genetic mutations and specific genetic variations in oncogenes and suppressor genes [3]. The high-risk areas are the floor of the mouth and the ventrolateral tongue, while the low-risk regions lie in the palatal mucosa and the tongue dorsum [4].

The key to OSCC management is early diagnosis and treatment. Targeting pre-malignant oral diseases has been regarded as a possible strategy for the early diagnosis of at-risk and high-risk patients, but it remains difficult to diagnose clinically [5,6]. The most common treatment for OSCC is surgical resection, but radiotherapy and chemotherapy are used preoperatively and postoperatively to reduce

Mechanical properties of 3 hydrophilic addition silicone and polyether elastomeric impression materials

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Statement of problem. New "hydrophilic" elastomeric impression materials have been introduced with the goals of reducing marginal voids and distortion in the impressions and improving the quality of gypsum dies, but there are insufficient data on the mechanical properties of these materials.

Purpose. Mechanical properties, including elastic recovery, strain in compression, tear energy, and tensile strength of 3 hydrophilic impression materials with low and high consistencies were compared.

Material and methods. Two addition silicone impression brands (Imprint II, 3M ESPE; Flexitime, Heraeus Kulzer) and a polyether brand (Impregum, 3M ESPE) were studied. Two consistencies of each material (light-body and heavy-body) were investigated. Elastic recovery (%) and strain in compression (%) were tested according to ISO 4823; tear energy (J/m^2) and tensile strength (MPa) were tested following Webber and Ryge's method and ASTM D412 (Test Method A), respectively. Five specimens were made for each group for a total of 24 groups and 120 specimens. Results were analyzed by 2-way analysis of variance, and Fisher's protected least significance difference intervals were calculated (α=.05). Correlation analysis was used to evaluate the relationships among properties.

Results. *P* values were smaller than .0001 for material, consistency, and interaction for strain in compression, tear energy, and tensile strength. For elastic recovery, *P* values were smaller than .0001 for material and the interaction between material and consistency, but equal to .4150 for consistency. Strain in compression correlated with other mechanical properties ($P<.05$), but tensile strength and tear resistance were not correlated.

Conclusions. In general, new "soft" polyether impression materials had higher strain in compression and lower tensile strength compared to new "hydrophilic" addition silicone materials. Heavy-body materials had higher tear properties and tensile strength than light-body materials. Strain in compression was correlated with elastic recovery, tear energy, and tensile strength. Tear resistance and tensile strength were not correlated.
(J Prosthet Dent 2004;92:151-4.)

CLINICAL IMPLICATIONS

The selection of an impression material for a particular application should be based on property data rather than on the type and class of the elastomeric impression material. Contrary to conventional belief, this study found that the new polyether consistencies (Impregum) were softer than addition silicone impression materials tested.

Addition silicone impression materials (vinyl polysiloxane, VPS) have been widely accepted due to excellent dimensional stability, superior recovery from deformation, and precise detail reproduction.[1] It is estimated that addition silicones have captured approximately half of the impression material market.[1] Addition silicones are intrinsically hydrophobic in nature, which can result in voids at the margin of the tooth preparation in the impression and bubbles in gypsum casts. Recently, addition silicone impression materials are being labeled as hydrophilic due to the addition of extrinsic surfactants. Surfactants are added to improve the wettability of oral tissue during impression making and of gypsum during pouring of the cast.[2,3]

Adequate mechanical properties ensure the impression material can withstand various stresses upon removal, while maintaining dimensional stability and integrity. ISO 4823 specifies the requirements for properties of elastomeric impression materials, including elastic recovery and strain in compression.[4] Elastic recovery is the ability of the impression material to

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Effect of saliva isolation and intraoral light levels on performance of intraoral scanners

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Introduction: The use of digital models in orthodontics is becoming increasingly widespread. This study aimed to evaluate the accuracy and performance of digital intraoral scanning under 4 different intraoral environmental conditions. **Methods:** Four digital models were acquired with TRIOS intraoral scanner (3Shape, Copenhagen, Denmark) for 50 subjects. A total of 200 digital models were divided into 4 groups as follows: daylight and saliva (group 1), daylight with saliva isolation (group 2), reflector light and saliva (group 3), and relatively dark oral environment and saliva (group 4). The 4 digital models were superimposed, and the edges of the models were trimmed to create common boundaries (Geomagic Control X; 3D Systems, Rock Hill, SC). Group 2 models were used as a reference and superimposed separately with the models of the other 3 groups. Deviations between corresponding models were compared as means of negative deviation, means of positive deviation, in total area, out total area, positively positioned areas, and negatively positioned areas. In addition, all groups were compared in terms of scanning time, the total number of images, and the mesiodistal width of teeth. **Results:** Overlapping of group 1 with the reference model (group 2), a surface deviation of 13.1% (out total area) was observed. This analysis revealed that a 13% deviation was caused by the presence of saliva alone. This rate was 12.6% in group 3 and 15.5% in group 4, respectively. The values for means of negative deviation were −55 μ in group 1, −63 μ in group 3, and −68 μ in group 4. Means of positive deviation values were distributed among groups as follows: 68 μ in group 1, 69 μ in group 3, and 78 μ in group 4. The total number of images was observed, at least in group 4. **Conclusions:** The intraoral scanner performance was affected by different environmental conditions, and that caused variations on the surface of digital models. However, the performance of the intraoral scanner was independent of the scanning time and mesiodistal width of the teeth. (Am J Orthod Dentofacial Orthop 2020;158:759-66)

Traditional plaster models are routinely used by orthodontists for diagnosis and treatment planning.[1] These models are convenient for 3-dimensional (3D) dentoalveolar diagnostic analysis. However, classical plaster models have disadvantages such as breakability, storage problem, cost, and laboratory procedure. In the 21st century, named digital age, technological devices have developed very rapidly, and the usage of plaster models has been replaced by 3D intraoral scanners (IOS).[2,3] A digital impression is obtained slower than the current alginate impression system because of longer scanning time, but patient compliance and acceptance are higher in the digital impression,[4,5] and it enables easy digital storage of data. In addition, 3D images obtained with these scanners might be used for digital model setup, customized bracket, and specialized appliance construction such as expanders, aligners, retainers. These advantages have made IOS widespread in the last 2 decades.

Thanks to specialized software, various analyses such as Bolton and Hayce-Nance could be made on digital study models.[6] In recent studies, the researchers tested the accuracy and reproducibility of these 3D images by using the software. The investigations were conducted either by comparing the performance of 2 different devices or by comparing the traditional plaster model to the IOS.[7,8]

Many factors affect the performance of intraoral scanners such as the presence of saliva or water, scanning path, increased curvature or complex geometry of

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Research Article

Accuracy on Scanned Images of Full Arch Models with Orthodontic Brackets by Various Intraoral Scanners in the Presence of Artificial Saliva

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Aim. This study aims to evaluate the accuracy of scanned images of 4 clinically used intraoral scanners (CS3600, i500, Trios3, Omnicam) when scanning the surface of full arch models with various kinds of orthodontic brackets in the presence of artificial saliva. *Materials and Methods.* Four study models were prepared; bonded with ceramic, metal, and resin brackets, respectively, and without brackets. Reference images were taken by scanning the models with an industrial scanner. Study models were then applied with an artificial saliva and scanned 10 times, respectively, with the above 4 intraoral scanners. All images were converted to STL file format and analyzed with 3D analysis software. By superimposing with the reference images, mean maximum discrepancy values and mean discrepancy values were collected and compared. For statistical analysis, two-way ANOVA was used. *Results.* Omnicam (1.247 ± 0.255) showed higher mean maximum discrepancy values. CS3600 (0.758 ± 0.170), Trios3 (0.854 ± 0.166), and i500 (0.975 ± 0.172) performed relatively favourably. Resin (1.119 ± 0.255) and metal (1.086 ± 0.132) brackets showed higher mean maximum discrepancy values. Nonbracket (0.776 ± 0.250) and ceramic bracket (0.853 ± 0.269) models generally showed lower mean maximum discrepancy values in studied scanners. In mean discrepancy values, the difference between scanners was not statistically significant whereas among brackets, resin bracketed models (0.093 ± 0.142) showed the highest value. *Conclusion.* Intraoral scanners and brackets had significant influences on the scanned images with application of artificial saliva on the study models. It may be expected to have similar outcomes in an intraoral environment. Some data showed the discrepancy values up to about 1.5 mm that would require more caution in using intraoral scanners for production of detailed appliances and records.

1. Introduction

The clinical usage of intraoral scanners has become more and more common. For the last decade, the effectiveness of intraoral scanners was studied to prove their practicability in various clinical settings [1–9]. Digital impression systems, when proving their credibility to replace conventional impression methods will benefit the orthodontic clinicians and patients. It has been shown that patients are generally satisfied and prefer recordings by intraoral scanners over conventional alginate impression technique [10]. They will help to save physical storage spaces and time since the treatment process requires multiple times of impression taking. Conventional impression technique results in more discomfort especially for the orthodontic patients due to the presence of brackets and wire and additional time and effort required because of that.

The scope of researches on intraoral scanning has been limited mostly to a prosthetic point of view [1, 3–9]. However, orthodontic conditions such as brackets and wires start to be included in more recent studies [11–15]. It is only that impression taking during orthodontic treatments involves several limitations due to intraoral conditions. Contamination of saliva on the teeth and the presence of various kinds of brackets is one of the intraoral conditions that may have direct impact on the accuracy of the scanned image [16, 17]. There was a study on the effect of water on the surface of dental restorative materials [18]. Design of the

Trueness of Intraoral Scanners Considering Operator Experience and Three Different Implant Scenarios: A Preliminary Report

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Purpose: To evaluate the trueness of two intraoral scanners in different clinical situations and considering operator experience. ***Materials and Methods:*** Two intraoral scanner systems were used to perform a total of 120 digital impressions of three master casts reproducing three scenarios (single implant, two implants, and four implants [full-arch]). Two operators, one experienced and one unexperienced, were selected. ***Results:*** No differences were found between the two operators. A statistically significant correlation was found with regard to the scanning system used and the clinical scenario analyzed. ***Conclusions:*** Within the limits of this preliminary report, operator experience seems not able to significantly influence the trueness of a digital impression; however, imprecision increased in the full-arch cases for both operators. The two-implant scenario presented similar trueness values for both scanner systems. *Int J Prosthodont 2020 (4 pages). doi: 10.11607/ijp.6224*

A precise impression is critical for fabricating dental restorations with adequate fit.[1,2] The introduction of digital impressions and scanning systems in dentistry in the mid-1980s created the expectation of eliminating errors that result from conventional impression techniques such as expansion, shrinkage, and distortion. Additionally, intraoral scanners (IOS) have been shown to be preferred by the patient in several clinical studies.[3–5] Conversely, the disadvantages of using digital impressions are the difficulty in detecting deep margin lines in prepared teeth and/or in the case of bleeding; the learning curve; and the purchasing and managing costs.[5] Moreover, as reported in a recent systematic review, the literature so far does not support the use of an IOS in long-span restorations.[5] Implant impressions, especially in edentulous patients, are the most challenging situation for an IOS due to the reduced number of reference points.

The aim of the present study was therefore to evaluate the trueness of two IOS systems considering operator experience and different clinical scenarios.

MATERIALS AND METHODS

Three master casts reproducing three different clinical situations made with an improved type IV die stone (GC Fujirock EP, GC America) were fabricated (Fig 1), and scan bodies were screwed (Sweden & Martina) on implant analogs.

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Accuracy of a Digital Impression System Based on Active Wavefront Sampling Technology for Implants Considering Operator Experience, Implant Angulation, and Depth

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ABSTRACT

Background: There is a scarce knowledge on the accuracy of intraoral digital impression systems for dental implants.

Purpose: The purpose of this study is to evaluate the accuracy of a digital impression system considering clinical parameters.

Materials and Methods: A master model with six implants (27, 25, 22, 12, 15, 17) was fitted with polyether ether ketone scan bodies. Implant no. 25 was placed with 30° mesial angulation in relation to the vertical plane (y axis), and implant no. 15 was positioned with 30° distal angulation. Implant no. 22 was placed 2 mm and no. 12, 4 mm below the gingiva. Experienced ($n = 2$) and inexperienced operators ($n = 2$) performed scanning (Lava Chairside Oral Scanner; 3 M ESPE, St Paul, MN, USA) at standard and high accuracy mode. Measurements involved five distances (27-25, 27-22, 27-12, 27-15, 27-17). Measurements with high accuracy three-dimensional coordinated measuring machine (CMM) of the master model acted as the true values. The data obtained were subtracted from those of the CMM values.

Results: Experience of the operator significantly influenced the results ($p = .000$). Angulation ($p = .195$) and depth of implant ($p = .399$) did not show significant deviation from the true values. The mean difference between standard and high accuracy mode was 90 µm.

Conclusions: With the active wavefront sampling, technology-based digital impression system training seems to be compulsory. Impressions of angulated implants may diminish the accuracy of the impression, yet the results were not significant.

KEY WORDS: accuracy, dental implant, digital impression, implant angulation, implant depth, intraoral scanner

INTRODUCTION

Obtaining absolute passive fit of the prosthetic framework on implants has been reported to be nearly impossible.[1] Because of the multiple steps involved in processing and manufacturing implant-borne prostheses, errors in precision seem to be unavoidable.[2,3] Misfit of prosthesis may lead to mechanical failures such as screw distortion and loosening, component fractures, and even implant failure.[4,5]

Multiple dental implants are generally splinted in order to resist against lateral and torque forces.[6,7] Splinting the implants may improve the distribution of masticatory loads, reduce mechanical complications,[8] decrease stress in peri-implant tissues,[9,10] necessitate less number of implants that eventually decrease the total

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Accuracy and precision of 3 intraoral scanners and accuracy of conventional impressions: A novel in vivo analysis method

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ABSTRACT

Objective: To evaluate a novel methodology using industrial scanners as a reference, and assess in vivo accuracy of 3 intraoral scanners (IOS) and conventional impressions. Further, to evaluate IOS precision in vivo.
Methods: Four reference-bodies were bonded to the buccal surfaces of upper premolars and incisors in five subjects. After three reference-scans, ATOS Core 80 (ATOS), subjects were scanned three times with three IOS systems: 3M True Definition (3M), CEREC Omnicam (OMNI) and Trios 3 (TRIOS). One conventional impression (IMPR) was taken, 3M Impregum Penta Soft, and poured models were digitized with laboratory scanner 3shape D1000 (D1000).

Best-fit alignment of reference-bodies and 3D Compare Analysis was performed. Precision of ATOS and D1000 was assessed for quantitative evaluation and comparison. Accuracy of IOS and IMPR were analyzed using ATOS as reference. Precision of IOS was evaluated through intra-system comparison.
Results: Precision of ATOS reference scanner (mean 0.6 μm) and D1000 (mean 0.5 μm) was high. Pairwise multiple comparisons of reference-bodies located in different tooth positions displayed a statistically significant difference of accuracy between two scanner-groups: 3M and TRIOS, over OMNI (p value range 0.0001 to 0.0006). IMPR did not show any statistically significant difference to IOS. However, deviations of IOS and IMPR were within a similar magnitude. No statistical difference was found for IOS precision.
Conclusion: The methodology can be used for assessing accuracy of IOS and IMPR in vivo in up to five units bilaterally from midline. 3M and TRIOS had a higher accuracy than OMNI. IMPR overlapped both groups.
Clinical significance: Intraoral scanners can be used as a replacement for conventional impressions when restoring up to ten units without extended edentulous spans.

1. Introduction

CAD/CAM was introduced in dentistry for single-unit restorations over thirty years ago, and advancements in technology has made it possible to produce complex multi-unit restorations on teeth and implants [1–4]. An essential part of the workflow was the indirect digitization process by laboratory scanners of gypsum models poured from traditional analogue impressions [5]. Parallel to this technology, CEREC, a commercialized intraoral scanner (IOS), made it possible to digitize the dental status in situ [6,7]. However, the early CEREC IOS were limited to single-tooth restorations and came as an integral part in a proprietary workflow accompanied by an in-house milling machine.

Since the late 2000's, there has been a rapid increase in the number of commercial IOS with scanners capable of capturing full dental arches [8]. Yet, with an open platform allowing for third-party CAD/CAM manufacturing, and rapid growth in the number of IOS, there is limited data to validate if IOS can replace conventional impressions.

Varying terminology exists in the science of metrology for explaining intra- and inter-system variations. Although some research groups in dental literature have used the ISO 5725 [8–14], this study has adopted the more common definition of accuracy and precision. Hence, accuracy being defined as the ability of a measurement to match the actual value, and precision defined as the ability of a measurement to be consistently reproduced.

Several in vitro studies have evaluated IOS applying methodology of 3D Compare Analysis based on varying software best-fit alignment, ranging from single-units to full dental arches [5,8–12,15]. Some studies comparing IOS and conventional impressions have found IOS to demonstrate a statistically significant lower accuracy [11,12]. However, variations in study design, execution and material properties pose

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Article

Comparison of Intraoral and Extraoral Digital Scanners: Evaluation of Surface Topography and Precision

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Abstract: The aim of this study was to evaluate the surface topography and the precision measurements of different intraoral and extraoral digital scanners. A reference model of a maxillary arch with four implant analogs was prepared and scanned by three intraoral and two extraoral scanners. The reference model was scanned fifteen times with each digital scanning system, investigating the surface topography and precision measurements for the same-arch and cross-arch measurements. The data was exported to 3D inspection and mesh-processing software (GOM Inspect, Braunschweig, Germany). Statistical analysis was performed using a one-way Analysis of Variance (ANOVA) with the Tukey method for pairwise comparisons. The effect of parameters on generating the surface topography was analyzed by Univariate Linear Regression Analysis. Of the scanner systems evaluated, iTero (IT) exhibited the most number of triangulation points, followed by Trios 3 Shape (TR) and Straumann Cares (SC). There were no significant differences observed in the surface topography when comparing flat and contoured surfaces, the anterior and posterior position, and interproximal areas. For the precision measurement in the same quadrant, no statistical difference was noted between intra- and extraoral scanners. However, the extraoral scanners showed substantially higher precision measurements for the cross-arch measurement. Surface topography did not correlate to precision. Rather, precision correlated with the scanning mechanism. For a quadrant scanning, both intraoral and extraoral scanners are recommended, but extraoral scanners are recommended for a full-arch scanning.

Keywords: digital dentistry; digital impression; surface topography; precision; accuracy

1. Introduction

Making conventional impressions and fabricating gypsum models involve clinical and laboratory procedures that may result in cumulative errors. These processing errors are largely inherent to the handling and properties of dental materials. The conventional approaches of a physical impression made with an elastomeric impression material may affect the treatment outcomes, including accuracy, efficiency, and patients' comfort level [1]. Despite these limitations, the conventional impression technique has been considered the gold standard in dentistry mainly due to cost-effectiveness [2].

The use of digital technology in dentistry has advanced rapidly in the past few decades. Developed in the 1950s, current CAD/CAM (computer-aided design and computer-aided manufacturing) technology has not only brought a paradigm shift in treatment workflows but also enhanced patient care. The technology has supported modeling, design, and fabrication of dental models and restorations [3]. Technological advancement in 3D imaging and the application of CAD/CAM has

Original Contributions

Clinical Dentistry

Local accuracy of actual intraoral scanning systems for single-tooth preparations in vitro

Moritz Zimmermann, Dr Med Dent; Andreas Ender, PD Dr Med Dent;
Albert Mehl, Prof Dr Med Dent Dr Rer Biol Hum

ABSTRACT

Background. The authors evaluated the local accuracy of intraoral scanning (IOS) systems for single-tooth preparation impressions with an in vitro setup.

Methods. The authors digitized a mandibular complete-arch model with 2 full-contour crowns and 2 multisurface inlay preparations with a highly accurate reference scanner. Teeth were made from zirconia-reinforced glass ceramic material to simulate toothlike optical behavior. Impressions were obtained either conventionally (PRESIDENT, Coltène) or digitally using the IOS systems TRIOS 3 and TRIOS 3 using insane scan speed mode (3Shape), Medit i500, Version 1.2.1 (Medit), iTero Element 2, Version 1.7 (Align Technology), CS 3600, Version 3.1.0 (Carestream Dental), CEREC Omnicam, Version 4.6.1, CEREC Omnicam, Version 5.0.0, and Primescan (Dentsply Sirona). Impressions were repeated 10 times per test group. Conventional (CO) impressions were poured with type IV gypsum and digitized with a laboratory scanner. The authors evaluated trueness and precision for preparation margin (MA) and preparation surface (SU) using 3-dimensional superimposition and 3-dimensional difference analysis method using (95% − 5%) / 2 percentile values. Statistical analysis was performed using Kruskal-Wallis test. Results were presented as median (interquartile range) values in micrometers.

Results. The authors found statistically significant differences for MA and SU among different test groups for both trueness and precision ($P < .05$). Median (interquartile range) trueness values ranged from 11.8 (2.0) μm (CO) up to 40.5 (10.9) μm (CEREC Omnicam, Version 5.0.0) for SU parameter and from 17.7 (2.6) μm (CO) up to 55.9 (15.5) μm (CEREC Omnicam, Version 5.0.0) for MA parameter.

Conclusions. IOS systems differ in terms of local accuracy. Preparation MA had higher deviations compared with preparation SU for all test groups.

Practical implications. Trueness and precision values for both MA and SU of single-unit preparations are equal or close to CO impression for several IOS systems.

Key Words. Intraoral scanning; accuracy; local accuracy; precision; trueness; preparation margin; computer-aided design and computer-aided manufacturing.

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Computer-aided design and computer-aided manufacturing (CAD-CAM) technology is used increasingly in restorative dentistry.[1] Digitalization of tooth geometries with optical devices, such as intraoral scanning (IOS) systems, represents the first step within the digital dental work flow. Availability of IOS systems has increased significantly in the past decade and improvements in both software and hardware components have been realized.[2] Researchers have found digital impressions with IOS systems to be a clinically acceptable alternative to conventional (CO) impression methods for the fabrication of single-tooth restorations and short fixed dental prostheses; however, limitations remain for larger implant-supported restorations and edentulous jaws.[3-6] Among the advantages described for IOS systems are time efficiency, increased patient comfort, and data fusion options within the CAD-CAM work flow.[7-9]

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RESEARCH AND EDUCATION

In vitro comparison of trueness of 10 intraoral scanners for implant-supported complete-arch fixed dental prostheses

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ABSTRACT

Statement of problem. Digital scanning systems have become popular, but whether these systems are adequate for complete-arch implant-supported fixed dental prostheses is unclear.

Purpose. The purpose of this in vitro study was to evaluate the trueness of 10 different dental intraoral scanners.

Material and methods. Six implant analogs were installed, and an edentulous mandibular model composed of scannable Type 4 gypsum was scanned with 10 different intraoral scanners (3D Progress, Omnicam, Bluecam, Apollo DI, Planscan, E4D Tech, TRIOS MonoColor Cart, TRIOS Color Cart, TRIOS Color Pod, Lythos), 10 times each after the scan body was placed on the implant abutments. The data obtained were then converted into standard tessellation language format. For the control group, the gypsum model was scanned with an industrial scanner (ATOS Core 80). For trueness, the dental and industrial scanning data packs were analyzed with 3D comparison software. Statistical analyses were performed by using the Kruskal-Wallis and Mann-Whitney U tests.

Results. When ranked according to their surface superimposition values, the Color POD, Omnicam, Apollo DI, Color Cart, MonoColor Cart, and Bluecam scanners were found within the range of 31 to 45 µm. This group was followed by E4D, 3D Progress, Lythos, and Planscan, which were found within the range of 82 to 344 µm according to the same criteria.

Conclusions. Some of the digital scanners had the necessary performance for the fabrication of complete-arch implant-supported fixed dental prostheses. However, the possibility of data loss producing artifacts should be considered. (J Prosthet Dent 2020;124:755-60)

For implant-supported fixed dental prostheses, the impression plays a direct role in the success of the treatment, as transferring the intraoral positional and angular data of the implants to the gypsum cast accurately is essential. The passive fit of the prosthesis depends on the impression step.[1-4]

Computer-aided design and computer-aided manufacturing (CAD-CAM) software programs and hardware have now made the planning, design, and manufacture of restorations possible in a much shorter time. Nevertheless, CAD-CAM prosthetic dentistry often still depends on obtaining a definitive cast from conventional impression procedures. The scanning of these casts with extraoral scanners and transferring them to the digital platform constitutes the first step of the CAD-CAM process. However, factors including errors from conventional impressions and casts, the need for cast storage, and patient discomfort during impression making are disadvantages of scanning conventional casts.[5-7]

CAD-CAM systems have been used reliably to fabricate tooth-supported or implant-supported fixed dental prostheses of up to 3 units.[7] Scanning larger areas increases the errors that result from merging multiple single images, causing image distortion and reducing accuracy.[8] Although intraoral scanners are typically used for smaller areas (fewer than 3 or 4 units),[9,10] studies

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THE JOURNAL OF PROSTHETIC DENTISTRY

SYSTEMATIC REVIEW

Intraoral scan bodies in implant dentistry: A systematic review

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ABSTRACT

Statement of problem. Intraoral scan body (ISB) design is highly variable and its role in the digital workflow and accuracy of digital scans is not well understood.

Purpose. The purpose of this systematic review was to determine the relevant reports pertaining to ISBs with regard to design and accuracy and to describe their evolution and role in the digital dentistry workflow. Special attention was placed on their key features in relation to intraoral scanning technology and the digitization process.

Materials and methods. A MEDLINE/PubMed search was performed to identify relevant reports pertaining to ISB usage in dentistry. This search included but was not limited to scan body features and design, scan body accuracy, and scan body techniques and the role of ISBs in computer-aided design and computer-aided manufacturing (CAD-CAM) processes. Commercially available scan bodies were examined, and a patient situation was shown highlighting the use of ISBs in the digital workflow.

Results. Deficiencies in the reports were found regarding various scan body topics, including ISB features/design, accuracy, and the role of ISBs in CAD-CAM processes.

Conclusions. ISBs are complex implant-positioning-transfer devices that play an essential role in the digital workflow and fabrication of accurately fitting implant-supported restorations. With scanner technology rapidly evolving and becoming more widespread, future studies are needed and should be directed toward all parts of the digital workflow when using ISBs. By understanding the basic components of ISBs and how they relate to digital scanning and CAD-CAM technology, more emphasis may be placed on their importance and usage in the digital workflow to ensure accurate transfer of implant position to the virtual and analog definitive cast. Efforts should be made by clinicians to identify an optimal ISB design in relation to the specific intraoral scanning technology being used. (J Prosthet Dent 2018;120:343-52)

Digital dental technology has evolved rapidly since the introduction of the computer-aided design and computer-aided manufacturing (CAD-CAM) process in the 1980s.[1] By definition, CAD-CAM consists of 3 elements: computer-aided data acquisition, data processing and design, and CAM.[2] By 2003, it became possible to use these 3 elements to scan and produce a 3-dimensional (3D) digital image which could be used to fabricate single-tooth restorations.[3] It was not long before computer-aided data acquisition was applied to other aspects in dentistry, including orthodontics, prosthodontics, and implant dentistry, through the use of digital scanning systems.

Dental impressions are a crucial step in implant dentistry.[4] Inaccurate transfer of the implant position can lead to an ill-fitting prosthesis, which may ultimately result in both biological and mechanical complications.[5] With the advent of CAD-CAM technology, it is now possible to use a digital workflow when fabricating implant-supported restorations,[6] which can be either direct or indirect in nature.[7,8] The indirect workflow involves making a conventional implant impression which is then digitized in the laboratory by using an optical benchtop scanner and laboratory scan bodies (ISBs). The direct workflow, however, includes the use of ISBs and an intraoral scanning device to generate a digital scan directly from the patient's mouth. Once captured accurately, a digital implant analog can then be placed in a digital model with specific implant/ISB libraries, and dentistry-specific CAD software is used in fabricating the restoration. Digital implant impressions offer advantages over conventional impressions including reduced risks of distortion during the laboratory phases; improved patient comfort and acceptance; and improved efficiency.[6] Although digital implant impressions have been well studied,[9-13] little has been reported about the

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Impact of Different Scan Bodies and Scan Strategies on the Accuracy of Digital Implant Impressions Assessed with an Intraoral Scanner: An In Vitro Study

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Keywords
Digital impressions; intraoral scan; precision; scan abutments; scanning procedure.

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The authors deny any conflicts of interest in regards to this study.

[Correction added on 27 January 2020 after first online publication: In the original publication, ELOS A/S was incorrectly referred to as "3Shape" The name has been corrected throughout the article.]

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Abstract

Purpose: Sufficient data are not currently available on how the various geometries of scan bodies and different scan strategies affect the quality of digital impressions of implants. The purpose of this study was to present new data on these two topics and give clinicians a basis for decision making.

Materials and Methods: A titanium master model containing three Nobelreplace Select™ implants (Nobelbiocare Services AG, Zurich, Switzerland) was digitized using an ATOS industrial noncontact scanner. Digitization was repeated three times with different types of scan bodies integrated into the implants: ELOS A/S, nt-trading GmbH, and TEAMZIEREIS GmbH. These three scans served as virtual master models. The titanium master model was then scanned with the TRIOS3© digital intraoral scanner (ELOS A/S, Copenhagen, Denmark), which was used for two different scanning strategies. Strategy A was a one-step procedure that included both the titanium master model and the integrated scan bodies. Strategy B comprised two steps. First, a digital overlay was performed with a scan of the titanium master model without integrated scan bodies. A second scan was performed with the titanium master model and integrated scan bodies. By repeating both strategies 10 times for each type of scan body, 60 scans were generated and the corresponding standard tessellation language data sets overlaid with the corresponding virtual master model. Deviations in the resulting superimpositions were calculated and evaluated separately in the individual axes (x, y, z) and in three-dimensional space (Euclidean distance). Statistical evaluation was performed using the R-project software. Level of significance was determined at $p \leq 0.05$.

Results: With regard to the geometry of the scan bodies, strategy A significantly influenced the accuracy of the digital implant impression in regards to Euclidean distance ($p = 0.003$). No significant difference was found for strategy B in this context. Comparing the two scan strategies revealed that strategy A achieved significantly higher accuracy overall ($p = 0.031$).

Conclusion: The quality of digital intraoral impressions seems to be influenced by both the geometry of the scan body and the scan strategy. For clinical practice, the one-step scan strategy seems beneficial. Furthermore, the scan bodies of ELOS A/S showed a potential clinical advantage.

In dentistry, implant-supported prostheses can be produced according to a conventional or digital workflow. In each case, impression making is the first step prior to the subsequent fabrication of a dental prosthesis.[1] Both processes have specific advantages and disadvantages. The conventional procedure is based on decades of experience and refined procedures, though mistakes still occur in the context of implant dentistry, such as displacement of scan abutments or dental stone expansion.[2,3] The digital workflow has advantages in reproducibility and quality standardization, but one main disadvantage is that deviations in the digital impression can lead to clinically unacceptable errors.[4,5]

CAD/CAM technology predominates the production process, as better quality control can be delivered with less time and material expenditure than conventional production (lost-wax fabrication method),[5] and can therefore be regarded as

Philipp Müller

Impact of digital intraoral scan strategies on the impression accuracy using the TRIOS Pod scanner

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Objectives: Little information is available on the impact of different scan strategies on the accuracy of full-arch scans with intraoral scanners. The aim of this in-vitro study was to investigate the trueness and precision of full-arch maxillary digital impressions comparing three scan strategies. **Method and Materials:** Three scan strategies (A, B, and C) were applied each five times on one single model (A, first buccal surfaces, return from occlusal-palatal; B, first occlusal-palatal, return buccal; C, S-type one-way). The TRIOS Pod scanner (3shape, Copenhagen, Denmark) with a color detector was used for these digital impressions. A cast of a maxillary dentate jaw was fabricated and scanned with an industrial reference scanner. This full-arch data record was digitally superimposed with the test scans (trueness) and within-group comparison was performed for each group (precision). The values within the 90/10 percentiles from the digital superimposition were used for calculation and group comparisons with nonparametric tests (ANOVA, post-hoc Bonferroni). **Results:** The trueness (mean ± standard deviation) was 17.9 ± 16.4 µm for scan strategy A, 17.1 ± 13.7 µm for B, and 26.8 ± 14.7 µm for C without statistically significant difference. The precision was lowest for scan strategy A (35.0 ± 51.1 µm) and significantly different to B (7.9 ± 5.6 µm) and C (8.5 ± 6.3 µm). **Conclusions:** Scan strategy B may be recommended as it provides the highest trueness and precision in full-arch scans and therefore minimizes inaccuracies in the final reconstruction. *(Quintessence Int 2016;47:343–349; doi: 10.3290/j.qi.a35524)*

Key words: accuracy, digital impression, intraoral scan, precision, strategy, trueness

An increasing number of dentists are using intraoral scanners in their daily practice as an alternative to conventional physical impression taking.[1] The introduction of intraoral impression taking allows for digitizing data as early as possible in the digital workflow, leading to greater productivity for the dentist and the technician. For short-span tooth or implant-based reconstructions within the same quadrant the risk of producing errors in the digitizing process is considered low, as the scan sensor captures a relatively large surface in relation to the total area required.[2,3] Several in-vitro studies have shown high levels of accuracy using different intraoral scanners.[2,4-6] However, systematic deviations may occur for full-arch scans, and the transfer to the clinical situation has not yet been investigated.[7] While the manufacturers provide information on the suggested method of performing the scans, the clinicians undergo a learning curve with a specific

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RESEARCH AND EDUCATION

Influence of operator experience, scanner type, and scan size on 3D scans

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ABSTRACT

Statement of problem. Intraoral scanners (IOSs) have some inherent distortions caused by optical and/or software imperfections. However, how other factors such as operator experience, scan time, scanner type, and scan size influence scan accuracy is not clear.

Purpose. The purpose of this in vitro study was to evaluate the trueness and precision of scans performed by 3 professionals with different levels of experience by using 2 IOSs.

Material and methods. Three operators with low, medium, and high levels of experience scanned a master model 10 times by using 2 IOSs (CEREC Omnicam; Dentsply Sirona and TRIOS 3; 3Shape), resulting in 10 standard tessellation language files for each group (N=60). Each standard tessellation language file was divided into 2 areas (prepared teeth and complete arch). Precision was evaluated by comparing the 10 scans from each examiner for each system. Trueness was evaluated by comparing each scan file with a reference scan obtained from a laboratory scanner (D2000; 3Shape). A 3D analysis software program (Geomagic Control; 3D Systems) was used to perform all the comparisons and superimpositions. The 3-way ANOVA test followed by the Tukey HSD test were used to assess precision and trueness. The 2-way ANOVA followed by the Tukey HSD test was used to assess scan time. The Pearson correlation test was performed between scan time and trueness for both scanners. An additional correlation was performed between scan time and number of images, as well as between number of images and trueness for the TRIOS 3.

Results. Statistically significant influences of operator ($P<.001$), scanner ($P<.001$), scan size ($P<.001$), operator and scan size ($P<.001$), and scanner and scan size ($P<.001$) were observed. The TRIOS 3 group reported higher precision than the CEREC Omnicam group for complete-arch scans ($P<.001$), although no difference was observed for scans of the prepared tooth. Medium- ($P=.002$) and low-experience operators ($P<.001$) reported lower precision for complete-arch scans performed with CEREC Omnicam when compared with TRIOS 3. The low-experience operator reported significantly worse results for complete-arch scans in comparison with the medium- ($P=.008$ and $P<.001$) and high-experience operators ($P<.001$ and $P=.001$), by using TRIOS 3 and CEREC Omnicam, respectively. Medium- and high-experience operators reported similar results among themselves. The CEREC Omnicam scanner reported lower trueness for complete-arch scans when compared with the prepared tooth ($P<.001$); for TRIOS 3, a difference was only observed for the low-experience operator when compared with the high-experience operator ($P<.001$). The CEREC Omnicam reported lower trueness than the TRIOS 3, except for the medium-experience operator with the prepared tooth scan. Comparing the trueness between operators and considering the same scanner and scan size, all groups were similar. The low-experience operator had a longer scanning time than the medium- and high-experience operators. For TRIOS 3, the low-experience operator obtained the highest number of images during each scan.

Conclusions. The accuracy of intraoral scans was influenced by operator experience, type of IOSs, and scan size. More experienced operators and smaller scan sizes made for more accurate scans. In addition, more experienced operators made faster scans, and the TRIOS 3 was more accurate than the CEREC Omnicam for complete-arch scans. (J Prosthet Dent 2020;■:■-■)

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Original article

Evaluating the influence of ambient light on scanning trueness, precision, and time of intra oral scanner

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ABSTRACT

Purpose: This study evaluated the influence of illuminance and color temperature of ambient light on the trueness, precision, and scanning time of a digital impression.
Methods: Master data were acquired with a high-accuracy coordinate-measuring machine. The illuminance of ambient light was set at 0 lux, 500 lux, and 2500 lux with a light-emitting diode (LED). Using a conversion filter, the color temperature was set at 3900 Kelvin (K) (yellow), 4100 K (orange), 7500 K (white), and 19,000 K (blue). There were thus a total of 12 possible lighting conditions. The reference model was scanned five times under each condition by an intraoral scanner. Trueness was calculated as the mean difference between the master data and experimental data. Precision was calculated as the mean difference between the repeated scans in each test group. Statistical analysis was performed with two-way analysis of variance (ANOVA) and post hoc Tukey's multiple comparison test. The significance level was 0.05.
Results: For trueness, the mean deviation was significantly lower at 500 lux than at 0 lux and 2500 lux. At 500 lux, the mean deviation was significantly lower at 3900 K than at other temperatures. Regardless of the color temperature, the scanning time was significantly longer at 2500 lux than at other illuminance levels.
Conclusions: The 3900 K and 500 lux condition is the most appropriate lighting condition for taking a digital impression. This condition is typical of clinical settings. High illuminance ambient light increased the scanning time.

1. Introduction

A digital impression has many benefits such as improving patient acceptance, reducing the distortion of impression materials, and three-dimensional previsualization of the preparation, and it is cost- and time-effective [1]. Moreover, a digital impression has high patient satisfaction because it does not involve noxious stimuli (e.g., suffocation hazard, gagging, and taste irritation) [2], and it reduces the clinical treatment time (e.g., retaking and curing time) [3–7].

The improved performance of intraoral scanners has led to a dramatic evolution in the accuracy of digital impressions. The accuracy of a digital impression is determined by trueness and precision [8]. Trueness is the deviation of the scanned data from the original geometry. Precision is the deviation between repeated scans of the same sample [9–11]. Some *in vitro* studies [10,11] have evaluated the trueness of digital impressions. In these studies on full arch impressions, the trueness of the digital impression was lower than that of the conventional method using polyvinyl silicone (PVS). However, other studies [12–17] have reported no significant difference in the marginal fit of crowns between crowns fabricated with a digital impression and crowns fabricated with the conventional method. Moreover, the investigators of these studies concluded that the accuracy of the marginal fit of crowns fabricated with digital impression was clinically acceptable. Some studies [10,11,16,17] have evaluated the precision of digital impressions. In *in vitro* studies [10,11] on full arch impressions, the precision of the digital impression was lower than that of the conventional method using PVS. One study [16] evaluated *in vivo*

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WILEY

RESEARCH ARTICLE

Outcomes of visual tooth shade selection performed by operators with different experience

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Abstract

Objective: To evaluate the effect of professional experience and lighting conditions on visual shade selection on natural teeth and comparing the visual-shade-selection results with those of instrumental methods.

Materials and Methods: Shade selection was performed on five maxillary central incisors. The 25 observers were divided into five groups according to their professional experience. Observers performed visual-shade-selection using shade guide (Vita 3D Master, Vita Zahnfabrik, Bad Säckingen, Germany) under two lighting conditions (4000 and 6500 K) from the cervical, middle and incisal thirds of the teeth. Same teeth were measured using an intraoral scanner (Trios 3Shape, Copenhagen, Denmark) and spectrophotometer (Vita Easyshade Compact, Vita Zahnfabrik, Bad Säckingen, Germany), under the same two lighting conditions.

Results: Visual-shade-selection outcomes were not affected by professional experience under both lighting conditions ($P < .05$). Outcomes of visual-shade-selection and intraoral scanner were not significantly different than that of spectrophotometer ($P > .05$). Lighting conditions had no effect on the shade measurement outcomes of visual shade selection, Vita Easyshade Compact, and Trios 3Shape ($P > .05$).

Conclusions: Shade measurement outcomes were not affected by the lighting conditions (4000 and 6500 K). The shade measurement feature of the T-3S could be an alternative to V-ES and VSS.

Clinical significance: This study suggests professional experience and lighting conditions has no effect on visual shade selection. Trios 3Shape could be used for shade determination as an alternative to a Vita Easyshade Compact spectrophotometer.

KEYWORDS
operator experience, shade selection, spectrophotometer, tooth color, visual shade selection

1 | INTRODUCTION

One of the most important step affecting the outcome of esthetic restorations is selecting the correct tooth shade.[1] Two methods can be used to select the tooth shade: visual and instrumental.[2] In dentistry, visual shade selection (VSS) using tooth shade guides is the most frequently used method.[3] However, VSS is a subjective method, which can be affected by many variables such as lighting conditions, the surroundings, age, gender, professional experience, and eye fatigue.[3] The lighting condition is critical because of the quality and intensity of the light reaching the teeth could influence to perceived shade of the tooth.[4,5] Although daylight is considered the standard compared with other light sources, direct sunlight should not be used for shade selection.[6] The

The study was approved by University Non-Interventional Clinical Research Ethics Committee (80558721/G288).

materials

MDPI

Article

Influence of Applied Liquid-Type Scanning-Aid Material on the Accuracy of the Scanned Image: An In Vitro Experiment

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Abstract: The study was designed to evaluate the effects of a liquid-type scanning-aid material on the accuracy and time efficiency of intraoral digital impressions compared to those of two different types of powder scanning-aid material and the powder-free scanning method. Three reference models (inlay, onlay, and bridge) were fabricated by a 3D printer and scanned with a model scanner to make the reference datasets. Four experimental groups (application of ScanCure, VITA, IP, and no treatment) were established, and the scans were acquired (each n = 5) using the Trios 3®(3 Shape, Copenhagen, Denmark). All scan data were digitally superimposed with the reference data (trueness, n = 5), and group comparisons were performed for each group (precision, n = 10). Time efficiency was evaluated by comparing the working times for scanning the models. The liquid-type ScanCure group showed fewer errors than the IP and VITA groups in all three reference models. Particularly, in the inlay model, the ScanCure group showed high accuracy compared to the powder-type groups (IP and VITA) with statistical significance ($p < 0.001$). The working time of the no-treatment group was longer than that of the agent groups in all reference models ($p < 0.001$). Notably, in the bridge model, the working time of the ScanCure group was shorter than that of the IP and VITA groups. Unlike other spray-type scanning-aid materials, this liquid-type material has the advantage of being thinly and uniformly applied to the object surface at the time of use. These findings suggest that the liquid-type scanning-aid material would be more accurate in achieving shape reproducibility using an intraoral scanner than the other two spray-type groups.

Keywords: intraoral scanners; trueness; precision; root mean square (RMS); scanning-aid materials

1. Introduction

In daily clinical practice, digital impression with an intraoral scanner has been widely used for its advantages in allowing for reduced storage space, short laboratory time, no distortion errors from the impression material, patient comfort, better hygiene, and long-term low cost [1–3].

Most dental intraoral scanners currently available on the market are powder-free types, which means that they do not require any scanning spray. However, their clinical efficiency is for only a short span [4,5]. It is challenging to quickly obtain accurate data over a long span, such as a complete arch [6–9]. Furthermore, in some clinical situations, it is challenging to obtain reliable and precise data for the necessary parts in the narrow and deep areas of the prepared teeth and prostheses using metallic materials because of the reflection of light, even though it is for a short span [10].