Accuracy of Intraoral Scanners and Conventional Impressions in Full-Arches: A Systematic Review

Exactitud de Escáneres Intraorales e Impresiones Convencionales en Arcadas Completas: Una Revisión Sistemática

Diego Salgueiro1;Ivana Quilodrán2 & Cristian Rosas3[3]

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ABSTRACT: The aim of this study was to evaluate intraoral scanners accuracy in full-arches, comparing them with conventional impressions. A scientific research performed in MEDLINE, EBSCOhost, and SciELO databases was conducted to analyze articles published between 2015 and 2020. Clinical and *in vitro* studies that evaluated accuracy (precision and trueness) from intraoral scanners and conventional impressions in full-arches were included. Two tests were applied to evaluate the methodological bias from the studies. Out of the 191 articles found, seven of them were selected for a qualitativeanalysis.In clinical studies,intraoral scanners CEREC Omnicam and 3Shape TRIOS Colorhad the highest precision compared to conventional irreversible hydrocolloid impressions. In i*n vitro* studies, conventional polyvinyl siloxane impressions showed the highest accuracy, followed by intraoral scanners Cadent iTero and CEREC Omnicam, while irreversible hydrocolloid impressions showed the lowest accuracy. Digital intraoral impression systems do not show superior accuracycompared to highly accurate conventional impression techniques. However, they provide excellent clinical results and both methods are clinically accepted.

KEY WORDS: intraoral scanners, conventional impressions, trueness, precision, accuracy, full-arch.

INTRODUCTION

An intraoral scanner (IOS) is a medical device which main goal is to record with precision the three-dimensional geometry of an object, it is composed of a handheld camera, a computer, and a software (Richert *et al*., 2017). IOSs eliminates the need for making a conventional impression, per se, eliminates various potential causes of error (such as inadequate tray selection, deformed elastic impressions, an incorrect powder–water ratio and inadequate storage of impressions or stone casts) that come into play during the process of conventional impression-taking and stone cast fabrication can be avoided (Hayama *et al*., 2018).

Studies focused on a single implant or tooth virtual impression have documented clinically acceptable values of accuracy, due to the limited extent of the restoration needed (Brawek *et al*., 2013; Ciocca *et al*., 2018). For long-span areas such as a complete arch, it has been demonstrated that first-generation IOS needed to improve to reach the accuracy levels of conventional impressions (Jeong *et al*., 2016).

In the last years, different IOS models have been released to the dentistry market as Medit i500 (2018), 3Shape TRIOS 4 (2019) and Primescan (2019). Consequently, the decision to search for articles published up to 5 years old was made.The purpose of this study was to evaluate IOSs accuracy in full-arches, comparing them with conventional impressions.

MATERIAL AND METHOD

A systematic review was developed following PRISMA guideline (Moher *et al*., 2009). The patient,

[1] School of dentistry, Faculty of Medicine, Universidad Austral de Chile, Valdivia, Chile.
[2] School of dentistry, Faculty of Medicine, Universidad Austral de Chile, Valdivia, Chile.
[3] Institute of Odontostomatology, Facultyof Medicine, Universidad Austral de Chile, Valdivia, Chile.

intervention, control, outcome (PICO) question was "In full-arch impressions, are intraoral scanners more accurate than conventional impressions, measured in microns?".

The inclusion and exclusion criteria are detailed in Table I.

Prior to the search, the reviewers were submitted to a calibration regarding the usage of search engines and the terminology related to the research topic. Two reviewers (I.Q., D.S.) performed the electronic search independently, on the databases MEDLINE, EBSCOhost and SciELO (Table II).

Three authors (I.Q., D.S., C.R.) evaluated the articles independently and screened the titles, abstracts and full text based on the eligibility criteria. Any disagreement on the eligibility of any article was solved by discussion and consensus.

Three of the authors (I.Q., D.S., C.R.) obtained the information independently, based on the relevant characteristics given in the selected articles.

The data obtained from clinical studies were the sample size, IOSs, conventional impression used and precision and/or trueness results represented in means and 95% Confidence Interval (CI).The data obtained from the *in vitro* studies were the reference model, IOSs, conventional impression used, and precision and trueness results represented in means and 95% CI. All the collected data was expressed in microns.

The device that using a hand-camera captures impressions and reproduces them digitally and three-dimensionally is defined as "IOS". These scanners can be used directly in the oral cavity of the patient or on reference casts. The impressions performed are stored as Standard Tessellation Language (STL). IOS current models were considered as CEREC Omnicam

Table I. Inclusion and exclusion criteria.

Inclusion criteria	Exclusion criteria
Articles published between September 2015 to September 2020.	Studies that only used scanners that previously needed powder spray or discontinued scanners from the market.
Studies in English.	Studies that fusion the images from Cone-Beam with the IOS.
In vitro or clinical studies.	
Studies that evaluated accuracy between IOSs and conventional impressions in complete dentated arches; partial dentated arches or edentulous arches.	
Studies that only compared IOSs with conventional impressions made of polyvinyl siloxane/silicone or irreversible hydrocolloid.	
The results had to be expressed as means and standard deviations or means and 95% CI, measured in millimeters or microns.	
The casts obtained by conventional impressions were to be digitized by a laboratory scanner.	

OS = Intraoral Scanner; CI = Confidence Interval.

Table II. Search strategy for each database and corresponding results.

Database	Search strategy	Number of results
MEDLINE (PubMed)	"Accuracy" AND ("Digital impression*" OR "i ntraoral scanner" OR "intraoral digital impression*") AND ("Conventional impression*" OR "analogue impression*") NOT "Cone beam"	47
EBSCO host (Dentistry & Oral Sciences Source)	Accuracy AND "intraoral scanner" OR "digital impression" AND "conventional impression" NOT "Cone beam".	168
SciELO	Accuracy AND digital impression AND conventional impression.	1

(Dentsply Sirona, NY, USA), Primescan (Dentsply Sirona, NY, USA), 3Shape TRIOS (3Shape, Copenhagen, Denmark), CS 3500 / CS 3600 (Carestream Dental, NY, USA), Cadent iTero (Align Technology, CA, USA), Medit i500 (Medit, Seoul, South Korea).

The physical impression obtained by a tray filled with impression material, either polyvinyl siloxane/ silicone or irreversible hydrocolloid, was defined as "Conventional impression". These conventional impressions reproduce in a three-dimensional manner and in negative, intraoral structures of patients on the clinical studies, or the structures of the reference casts on the *in vitro* studies.

A complete dentated arch was defined as the maxillary/mandibular arch with no missing teeth (excluding third molars); a partial dentated arch was defined as the maxillary/mandibular arch with at least 1 tooth missing (excluding third molars) and an edentulous arch was defined as the maxillary/ mandibular arch with all teeth missing.

Accuracy is composed of two independent concepts: "Precision" was defined as the process of superimposing digital casts of a same group on a specialized software and evaluating if reproducibility exists between them. "Trueness" was defined as the process of superimposing the digital casts of the test

group, individually, with the reference cast and evaluating if the obtained values on the test group are real or accepted from the reference.

In relation to the risk of methodological bias, the QUADAS test "Quality Assessment of Diagnostic Accuracy Studies" was used for clinical studies (Whiting *et al*., 2003). It includes 14 relevant questions to determine the risk of bias of the included articles, with answers "yes", "no" or in the case that is unknown, "unclear". If the question did not apply to the evaluated study, it was answered as "not applicable" and for the final score this was not considered.

For *in vitro* studies, a test created by two of the authors was used (I.Q., D.S.), where questions were adapted from the QUADAS test. It includes 5 questions focused on the reference casts, study tests and results. It considered the same answers of the QUADAS test, except for "unclear".

RESULTS

After database screening and the removal of duplicates, 191 articles were retrieved. Forty-three articles were discarded after language and title screening, 84 after examining abstracts, and 57 after full text reading. Finally, seven articles were included in the systematic review and meta-analysis. Two studies focused only on evaluating precision, while the other five evaluated accuracy as a conceptof precision and trueness (Fig. 1).
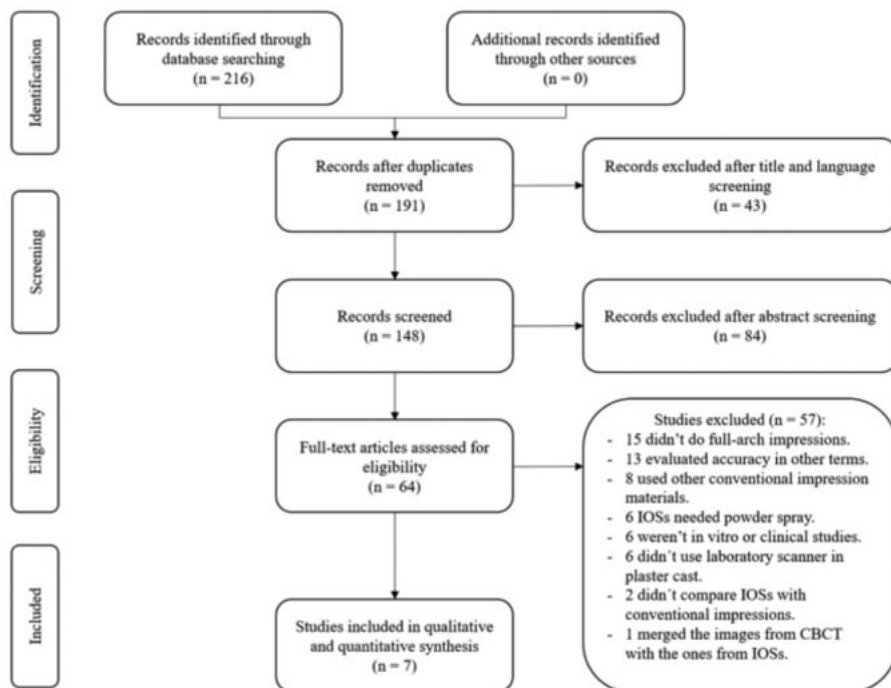

Fig. 1. Flow diagram of study identification.
IOSs = Intraoral Scanners; CBCT = Cone Beam Computed Tomography.

Although the clinical studies resulted in an acceptable methodology, they had limitations in relation to the selection criteria and withdrawals from the study. Nevertheless, all 3 studies showed a low bias index (Table III).

For the *in vitro* studies, they also resulted with acceptable methodology and presented limitations in relation to the description and standardization of the reference models used and in the description of the study tests to allow their replication (Table IV).

While each study performed its own "accuracy" method to evaluate the deviations of the casts, they followed the same sequence: On the one hand, the digital impressions were made with the IOSs, and the casts were obtained as STL files. On the other hand, conventional impressions were taken, which were

Table III. QUADAS analysis for clinical studies.

	Zimmermann *et al.,* 2017	Ender *et al.,* 2016	Gan *et al.,* 2016
1. Was the spectrum of patients representative of the patients who will receive the test in practice?	Y	Y	Y
2. Were selection criteria clearly described?	N	N	Y
3. Is the reference standard likely to correctly classify the target condition?	Y	Y	Y
4. Is the time between reference standard and index test short enough to be reasonably sure that the target condition did not change between the two tests?	Y	Y	Y
5. Did the whole sample or a random selection of the sample, receive verification using a reference standard of diagnosis?	Y	Y	Y
6. Did patients receive the same reference standard regardless of the index test result?	Y	Y	Y
7. Was the reference standard independent of the index test (the index test did not form part of the reference standard)?	Y	Y	Y
8. Was the execution of the index test described in sufficient detail to permit replication of the test?	Y	Y	Y
9. Was the execution of the reference standard described in sufficient detail to permit its replication?	Y	Y	Y
10. Was the execution of the reference standard described in sufficient detail to permit its replication?	Y	Y	Y
11. Were the reference standard results interpreted without knowledge of the results of the index test?	Y	Y	Y
12. Were the same clinical data available when test results were interpreted as would be available when the test is used in practice?	Y	Y	Y
13. Were uninterpretable/ intermediate test results reported?	Y	Y	Y
14. Were withdrawals from the study explained?	N	Y	Y
Score	12/14	13/14	14/14

Y= yes; N= no; U= unclear; N/A= not applicable.

Table IV. Bias test analysis for in vitro studies.

	Sim *et al.,* 2019	Ender *et al,* 2019	Malik *et al,* 2018	Ender & Mehl, 2015
1. Were the characteristics of the reference model clearly described?	Y	N	Y	Y
2. Was the manufacture of the reference model standardized to allow its replication?	Y	N	N	Y
3. Were the study tests clearly described to allow replication?	Y	Y	N	N
4. Were the study tests done independently? (Elements of the study tests did not form part of the reference test).	Y	Y	Y	Y
5. Were uninterpretable/ intermediate test results reported?	Y	Y	Y	Y
Score	5/5	3/5	3/5	4/5

Y= yes; N= no; N/A= not applicable.

emptied in type IV plaster and later scanned by a laboratory scanner to obtain the casts in STL format as well as the digital impressions. Then, all the STL files were imported to a specialized software to make their respective superimpositions based on the "best-fit algorithm". Deviations were calculated and finally exported to a statistical program for further analysis (Tables V and VI).

Zimmermann *et al*. (2017) recruited five volunteers with complete maxillary dentition that received conventional irreversible hydrocolloid impressions (Blueprint Cremix; Dentsply Sirona) and intraoral scans with CEREC Omnicam. Each method was performed three times per volunteer. CEREC Omnicam group was statistically significantly more precise than the Irreversible hydrocolloid group with 74.50

Table V. Results of clinical studies.

Author, year	N / Dentition	Results Mean (CI 95%)
Zimmermann *et al.*, 2017	N = 5 Complete dentated arch	Precision: .IH = 162.20 _m (126.12 - 198.28) .CEREC Omnicam = 74.50 _m (54.66 - 94.34)
Ender *et al.*, 2016	N = 5 Complete dentated arch	Precision: . IH = 162.20 _m (126.12 - 198.28) .CEREC Omnicam = 48.60 _m (42.73 - 54.47) .CadentiTero = 68.10 _m (58.54 - 77.66) .3Shape TRIOS = 47.50 _m (36.67 - 58.33) .3Shape TRIOS Color = 42.90 _m (32.58 - 53.22)
Gan *et al.*, 2016	N= 32 Complete dentated arch	Precision: . 3Shape TRIOS 3 = 59.52 _m (57.26 - 61.78) Trueness: . 3Shape TRIOS 3 = 80.01 _m (76.45 - 83.57)

N = Sample size; CI = Confidence interval; IH = Irreversible hydrocolloid; PS = Polyvinyl siloxane.

Table VI. Results of *in vitro* studies.

Author, year	RM	Precision Mean (CI 95%)	Trueness Mean (CI 95%)
Sim *et al.*, 2019	Partial dentated	. PS = 22,79 _m (18.80 - 26.78) . CS 3500 = 34.07 _m (30.03 - 38.11)	. PS = 28.49 _m (27.28 - 29.70) . CS 3500 = 28.09 _m (26.63 - 29.55)
Ender *et al*, 2019	Completed entated arch	. PS = 12.00 _m (9.40 - 14.60) . 3Shape TRIOS 3 = 51.30 _m (37.60 - 65.00) . CS 3600 = 63.20 _m (47.02 - 79.38) . Medit i500 = 66.30 _m (50.03 - 82.54) . iTero Element 2 v 1.7 = 66.00_m (46.79 - 85.21) . CEREC Omnicam v. 4.6.1 = 41.20_m (33.76 - 48.64) . CEREC Omnicam v. 5.0.0 = 43.70_m (33.97 - 53.43) . Primescan = 31.30 _m (24.92 - 37.68)	. PS = 16.20 _m (15.21 - 17.19) . 3Shape TRIOS 3 = 50.50 _m (44.55 - 56.45) . CS 3600 = 61.40 _m (50.68 - 72.12) .Medit i500 = 93.10 _m (80.58 - 105.62) . iTero Element 2 v 1.7 = 60.70 _m (53.57 - 67.83) . CEREC Omnicam v. 4.6.1 = 87.30 _m (75.83 - 98.77) . CEREC Omnicam v. 5.0.0 = 49.70 _m (44.25 - 55.15) . Primescan = 33.90 _m (29.07 - 38.73)
Malik *et al*, 2018	Partial dentated arch	. PS = 21.70 _m (16.67 - 26.73) . 3Shape TRIOS 3 = 49.90 _m (33.86 - 65.94) . CEREC Omnicam = 36.50 _m (26.68 - 46.32)	. PS = 24.30 _m (19.30 - 29.30) . 3Shape TRIOS 3 = 87.10 _m (80.18 - 94.02) . CEREC Omnicam = 80.30 _m (69.69 - 90.91)
Ender & Mehl, 2015	Complete dentated arch	. IH = 59.60 _m (21.38 - 97.82) . CEREC Omnicam = 35.50 _m (25.51 - 45.49) . CadentiTero = 36.40 _m (17.47 - 55.33)	. IH = 37.70 _m (7.11 - 68.29) . CadentiTero = 32.40 _m (26.18 - 38.62) . CEREC Omnicam = 37.30 _m (36.05 - 38.55)

RM = Reference model; CI = Confidence interval; PS = Polyvinyl siloxane; IH = Irreversible hydrocolloid.

mm (54.66 - 94.34) against 162.20 mm (126.12 - 198.28) respectively.

Ender *et al*. (2016) recruited five volunteers with complete maxillary dentition, that received conventional irreversible hydrocolloid impressions (Blueprint Cremix; Dentsply Sirona) and impressions with four IOSs of interest for this study, Cadent iTero; 3Shape TRIOS; 3Shape TRIOS Color and CEREC Omnicam. Each method was performed three times per volunteer. Irreversible hydrocolloid group with 162.20 mm (126.12 - 198.28) of precision showed, with statistically significant difference, less precise than the other groups. Among the IOS groups, the 3Shape TRIOS Color group with 42.90 mm (32.58 - 53.22) was more precise, but without a statistically significant difference.

Gan *et al*. (2016) investigated trueness and precision of 3Shape TRIOS 3and compared it, using as reference and not as another sample group, with the casts obtained by conventional polyvinyl siloxane impressions (Honigum Putty/Light; DMG, Hamburg, Germany). The researchers recruited 32 volunteers with complete maxillary dentition and made 3 impressions with 3Shape TRIOS 3 and 1 conventional impression for each volunteer. The group 3Shape TRIOS 3 presented a precision of 59.52 mm (57.26 - 61.78) and a trueness of 80.01 mm (76.45 - 83.57).

Sim *et al*. (2019) compared the accuracy of CS 3500, with conventional polyvinyl siloxane impressions (Honigum Light Body, Heavy Body; DMG). A partially dentated reference model was used, with preparations on the maxillary right first molar for unitary fixed prosthesis, maxillary right first premolar and maxillary right first molar for partial fixed dental prosthesis and maxillary left first molar for ceramic inlay. Each impression technique was made 8 times on the cast. Both groups did not present significant differences in terms of trueness, but they did at a precision level where the Polyvinyl siloxane group presented itself more precisely with 22.79 mm (18.80 - 26.78) while the group CS 3500 presented itself with 34.07 mm (30.03 - 38.11).

Ender *et al*. (2019) compared seven IOSs, 3Shape TRIOS 3; CS 3600; Medit i500; iTero Element 2; CEREC Omnicam v. 4.6.1; CEREC Omnicam v. 5.0.0 and Primescan, all with polyvinyl siloxane impressions (President 360 Heavy body and President light body; Coltène AG, Altstätten, Switzerland). They used a complete dentated arch reference cast with feldspathic ceramic teeth, because of their optical conditions like the natural tooth. They made 10 scans with each scan-

ner and 10 conventional impressions. The Polyvinyl siloxane group was significantly more accurate than all the IOS groups, with a precision of 12.0 mm (9.40 - 14.60) and a trueness of 16.20 mm (15.21 - 17.19). Within the IOS groups, the most accurate was the Primescan group, with 31.30 mm (24.92 - 37.68) for precision and 33.9 mm (29.07- 38.73) for trueness. On the other hand, the Medit i500 group was the least accurate, with 66.30 mm (50.03 - 82.54) for precision and 93.10 mm (80.58 - 105.62) for trueness.

Malik *et al*. (2018) compared two IOSs, 3Shape TRIOS 3 and CEREC Omnicam, with polyvinyl siloxane impressions (Aquasil Ultra; Dentsply Sirona). They used a partial dentated arch reference cast, with 7 teeth. They made 5 scans with each scanner and 5 conventional impressions on the cast. The Polyvinyl siloxane group, with 21.70 mm (16.67 - 26.73), was significantly more precise than CEREC Omnicam with 36.50 mm (26.68 - 46.32) and 3Shape TRIOS 3 with 49.90 mm (33.86 - 65.94). Both groups of scanners did not have statistically significant differences. The Polyvinyl siloxane group also presented significantly more trueness than both IOS groups, with 24.30 mm (19.30 - 29.30), while the CEREC Omnicam group presented with 80.30 mm (69.69 - 90.91) and 3Shape TRIOS 3 with 87.10 mm (80.18 - 94.02).

Ender & Mehl (2015) used a maxillary reference cast with a complete dentated arch with crowns and inlay preparations. They used 2 IOSs of interest for this study, CEREC Omnicam and Cadent iTero, and conventional irreversible hydrocolloid impressions (Blueprint Cremix; Dentsply Sirona). Five scans were performed with each scanner and 5 irreversible hydrocolloid impressions were performed on the cast. The CEREC Omnicam group was more precise, with 35.50 mm (25.51 - 45.49), but this difference was not statistically significant compared to the Cadent iTero group with 36.40 mm (17.47 - 55.33) or the irreversible hydrocolloid group with 59.60 mm (21.38 - 97.82). There were no significant differences in trueness between the groups, where the irreversible hydrocolloid group showed values of 37.70 mm (7.11 - 68.29), the CEREC Omnicam group of 37.30 mm (36.05 - 38.55) and the Cadent iTero group of 32.40 mm (26.18 - 38.62).

DISCUSSION

In relation to the methodology of the selected studies, they carried out the comparison of both

impression methods, in complete and partially dentate arches. The clinical studies used conventional impressions as the control group and IOSs as the test group (Ender *et al*., 2016; Gan *et al*.; Zimmermann *et al*.). The *in vitro* studies used the scanning of the fabricated cast from a laboratory scanner as the reference, and IOSs and conventional impression groups as tests (Ender & Mehl; Ender *et al*., 2019; Malik *et al*.; Sim *et al*.). However, to make the comparisons, all the studies followed the same sequence,converting the gypsum casts from conventional impressions into digital casts, just like those from the IOSs, and finally superimposing these as appropriate.

The results of this review reported statistically significant differences in precision and trueness between conventional irreversible hydrocolloid impressions and IOSs. The highest precision mean value of irreversible hydrocolloid impressions was 59.60 mm (Ender & Mehl) and the lowest was 162.20 mm (Zimmermann *et al*.; Ender *et al*., 2016). The only trueness mean value of irreversible hydrocolloid impressions was 37.70 mm (Ender & Mehl). On the other hand,the highest precision mean value of IOSs impressions was CEREC Omnicam's35.50 mm (Ender & Mehl) and the lowest was CEREC Omnicam's 74.50 mm (Zimmermann *et al*.). The highest trueness mean value of IOSs impressions was CS 3500's 28.09 mm (Sim *et al*.) and the lowest was Medit i500's 93.10 mm (Ender *et al*., 2019).

Conventional impressions made of polyvinyl siloxane, had the greatest mean values of precision and accuracy. The highest precision mean value was 12.00 mm (Ender *et al*., 2019) and the lowest was 22.79 mm (Sim *et al*.). The highest trueness mean value was 16.20 mm (Ender *et al*., 2019) and the lowest was 28.49 mm (Sim *et al*.).

Despite being the accuracy of IOSs certainly lesser than the accuracy of conventional impressions, digital scanning systems could be clinically sufficient in some cases such as orthodontic impressions (Duvert & Gebeile-Chauty, 2017), surgical implant guide fabrication (Rutku̅nas *et al*., 2017), pediatric dentistry (Yilmaz & Aydin, 2019) and immediate dentures fabrication (Fang *et al*., 2018).

In relation to the alterations of accuracy found in the IOSs, 3 studies presented patterns of deviation towards distal end of the dental arch, which could be explained by the difficult access to the area and saliva control, making *in vivo* scanning much more difficult and less accurate overall (Ender & Mehl; Ender *et al*., 2016; Zimmermann *et al*.). Five studies showed that the pattern of deviation was found in the anterior arch area, because the incisal edges present little geometric information, making it difficult to scan the area (Ender & Mehl; Ender *et al*., 2016, 2019; Gan *et al*.; Malik *et al*.).

Regarding the alterations in the accuracy of conventional impressions, 3 studies indicated that irreversible hydrocolloid presented deviations in specific irregular areas, due to the internal tearing of the material, by compression and stretching forces, when the tray was removed (Ender & Mehl; Ender *et al*., 2016; Zimmermann *et al*.). One study indicated that silicone presented deviations in molar fissures, due to the presence of air bubbles (Malik *et al*.).

It should be noted that accuracy is not the only factor that determines the success of the treatment, it is also patient comfort, cost-benefit, work time, among others, therefore these variables should not be overlooked.

It is necessary for dentists to respect the scanning protocols provided by the manufacturers of each brand of IOSs, so that the scans can be replicated between different professionals.

CONCLUSION

It can be concluded from this study that digital scanning systems were not superior to conventional polyvinyl siloxane impression systems but had better accuracy results than irreversible hydrocolloid impressions. Because of this, IOSs full-arch impressions could replace some conventional impression systems in certain clinical scenarios where there is no need of an excellent accuracy. However, better quality studies comparing the accuracy of IOSs and conventional impressions in different clinical settings are required.

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RESUMEN: El objetivo de este estudio fue evaluar la exactitud de escáneres intraorales en impresiones digitales de arco completo en comparación con las impresiones convencionales. Se realizó una revisión sistemática en las ba-

ses de datos MEDLINE, EBSCOhost y SciELO para analizar artículos publicados entre los años 2015 y 2020. Se incluyeron estudios clínicos e *in vitro* que evaluaran exactitud (precisión y/o veracidad) de escáneres intraorales impresiones convencionales en arcos completos. Dos pautas se aplicaron para evaluar el riesgo de sesgo de los estudios. De 191 artículos encontrados, 7 fueron seleccionados para un análisis cualitativo.En los estudios clínicos, los escáneres intraorales CEREC Omnicam y 3Shape TRIOS Color presentaron la mayor precisiónen comparación con las impresiones convencionales de hidrocoloide irreversible. En los estudios *in vitro*, las impresiones de polivinil siloxano presentaron la mayor exactitud seguido por los escáneres intraorales CadentiTero y CEREC Omnicam, mientras quelas impresiones de hidrocoloide irreversible presentaron la menor exactitud. Los sistemas de impresión digital intraoral no mostraron tener una exactitud superior comparados con las técnicas de impresión convencional de gran exactitud. Sin embargo, proveen excelentes resultados clínicos y ambos métodos son clínicamente aceptables.

PALABRAS CLAVE: escáner intraoral, impresión convencional, veracidad, precisión, exactitud, arco completo.

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Corresponding author:
Dr. Diego Salgueiro Castillo
School of dentistry
Faculty of Medicine
Universidad Austral de Chile
Valdivia
CHILE

E-mail: diegosalgueiroc@gmail.com