The Saudi Dental Journal (2023) **35**, 437–442

King Saud University

The Saudi Dental Journal

www.ksu.edu.sa
www.sciencedirect.com

REVIEW ARTICLE

Clinical aspects of digital three-dimensional intraoral scanning in orthodontics – A systematic review

Ahmed Mohammed Alassiry *

Faculty of Dentistry, Najran University, Saudi Arabia

Received 13 March 2023; revised 26 April 2023; accepted 27 April 2023
Available online 4 May 2023

KEYWORDS

Digital scanner;
Intraoral scanning;
Digital impression;
Accuracy;
Patient comfort;
Systematic review

Abstract *Objective:* This systematic review aimed to investigate the accuracy, reproducibility, scanning time, patient comfort, and operator experience of various commercially available intraoral scanners (IOS) in orthodontics.

Methods: An elaborate and extensive search of literature in the PubMed, Scopus, Google Scholar, Embase, Web of Science, and Cochrane Central databases was performed using various relevant keywords.

Results: A total of 3256 articles were obtained from all the databases, 35 studies were included. The accuracy of IOS was controversial compared to that of conventional impression techniques. Digital scanning demonstrated satisfactory to excellent reproducibility, shorter scanning time, and improved patient comfort compared with conventional techniques.

Conclusion: IOS are time-efficient, comfortable for patients, and simple to use with a learning curve for the operator. These methods are sufficiently accurate for treatment planning and aligner fabrication in orthodontics.

Contents

* Corresponding author.
E-mail address: amyahia@nu.edu.sa.

Peer review under responsibility of King Saud University. Production and hosting by Elsevier.

Production and hosting by Elsevier

https://doi.org/10.1016/j.sdentj.2023.04.004

1. Introduction

Study models are the basic pillars of diagnosis and treatment planning in orthodontics. The gold standard for obtaining conventional impressions is the use of elastomeric materials or custom trays (Ender et al., 2013). Orthodontic science advanced with the introduction of computer-aided design and computer-aided manufacturing in 1973 (Harrell et al., 2018). In the following years in 1987, the Chairside Economical Restoration for Esthetics Ceramics (CEREC) system was introduced as a prototype for digital impression (Logozzo et al., 2014). The first in-office commercial digital scanning system with full-arch scanning by the Cadent iTero became available on the market in 2008 (Morris et al., 2010). Since then, various digital intraoral scanning systems, scanners, and setups have been introduced and implemented in dentistry (Zimmermann et al., 2015).

Intraoral scanners (IOS) are noninvasive devices which capture optical impressions of dental arches and tissues when light is projected onto them (Ting-Shu et al., 2015). Images from the projected light are captured by imaging sensor cameras and sent to the software for processing. The software then creates a cloud of polygonal mesh points that represent three-dimensional (3D) surface models of the teeth and tissue. The mesh is further processed and refined to produce a final 3D image of the scanned object (Logozzo et al., 2014; Martin et al., 2015). This image is a replica of the intraoral teeth and tissue presented digitally on the screen, rather than traditional stone or plaster models (Aragón et al., 2016). The different optical properties of hard and soft tissues and saliva assist in the standardization of surfaces scanned (Logozzo et al., 2011). The data are stored in.stl file format and can be transferred via digital media anywhere worldwide. These optical impressions can be used to create treatment plans and virtual setups as well as fabricate customized orthodontic appliances, lingual brackets, and aligners in orthodontics (Hajeer et al., 2004; Marcel et al., 2001).

The amalgamation of IOS with orthodontics is a developing practice on a daily basis. Many studies have explained the various uses, advantages, and disadvantages of IOS in orthodontic practice. The clinical aspects of any IOS depend on its features, such as accuracy, reproducibility, scanning time, patient comfort, and operator experience. This systematic review aims to critically evaluate the features of various commercially available IOS and published studies. Additionally, it aims to elucidate the various aspects associated with IOS for regular clinical use and their practical applicability in everyday orthodontic practice.

2. Methods

2.1. Study selection

Various electronic databases, including PubMed, Scopus, Google Scholar, Embase, Web of Science, and Cochrane Central, were searched from inception to December 31, 2022. The keywords "intraoral scanner", "intraoral scanning", "digital impression", "digital scanner", "digital scanning", "three-dimensional scanner", "three-dimensional scanning", and "3D orthodontics" were used to identify relevant publications. No restrictions were set on study design, type, year of publication, or publication status. Studies involving dry skulls, phantom heads, reference models, and animals were excluded. Only full-text articles published in English were included.

2.2. Search outcomes

Subsequently, all relevant articles were screened. Irrelevant titles and abstracts were excluded from analysis. The review was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines (Moher et al., 2009), and the study flowchart is presented in Fig. 1.

2.3. Data extraction

The selected studies were then subjected to data extraction for accuracy, reproducibility, scanning time, patient comfort, and operator experience with IOS. Data entry was performed by two examiners, and any disagreements between them were discussed further to reach a consensus.

3. Results

3.1. Study characteristics

A total of 3256 articles were obtained from all the databases. After removing duplicates, unrelated, and irrelevant articles, the total number of articles decreased to 45, of which 10 were

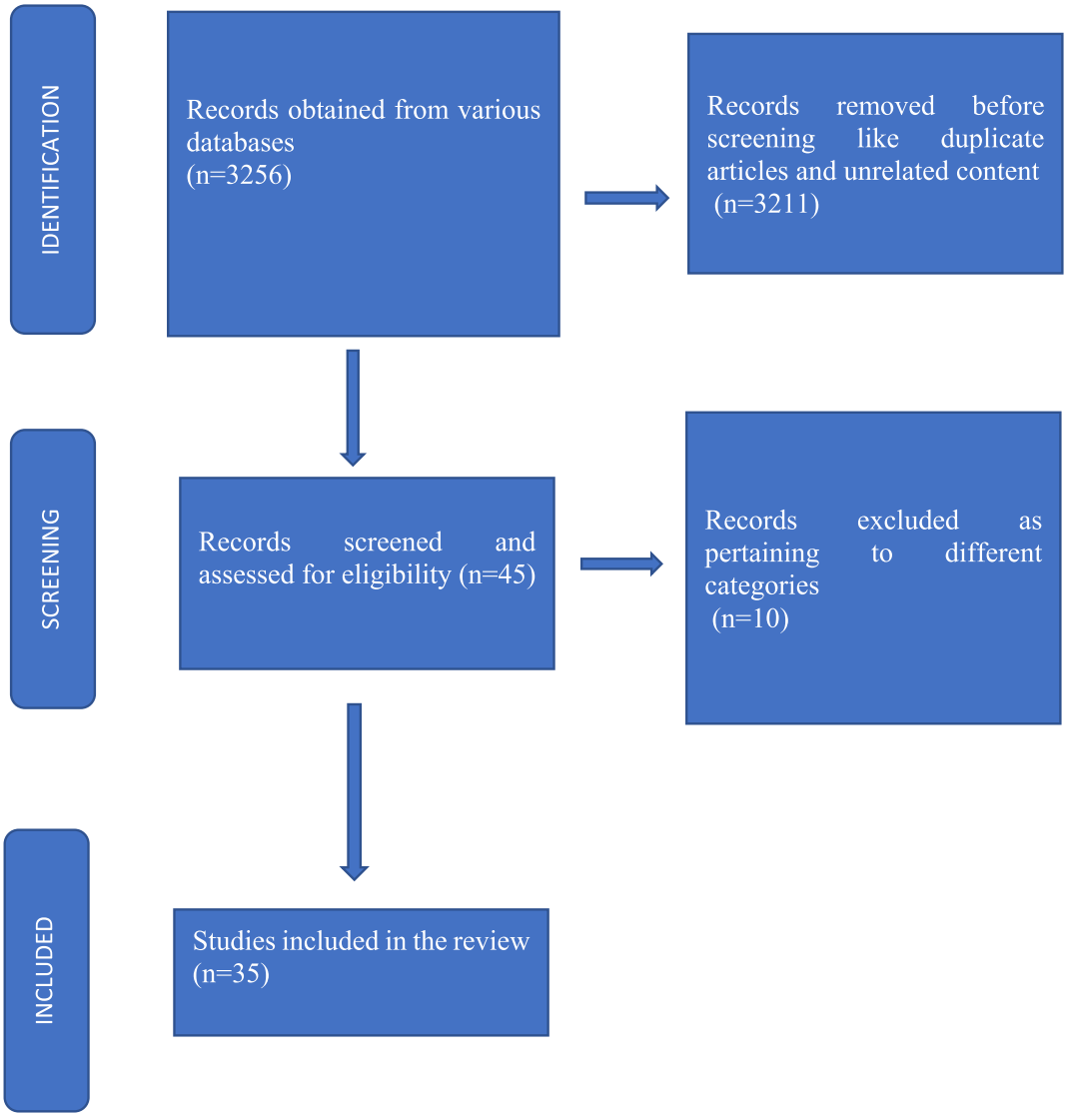

Fig. 1 PRISMA flowchart of the systematic review.

Table 1 Clinical features of Conventional and Digital impression methods.

	Conventional Impression	Intraoral Scanning	Contradictory Results
Accuracy	–	–	Unclear for both
Reproducibility	–	Excellent	–
Scanning time	–	–	Unclear for both
Patient comfort	–	Excellent	–
Operator experience	–	Excellent	–

further excluded according to different categories. Ultimately, 35 studies were included (Fig. 1). The clinical features of conventional and digital impression methods used in this study are listed in Table 1.

3.2. Accuracy of IOS

Wide variation in the reporting accuracy of IOS has been observed in the literature. Winkler and Gkantidis reported that TRIOS 3 (3Shape) demonstrated a slightly higher precision (approximately 10 μm) than CS 3600 (Carestream) only after superimposition on the whole dental arch (Winkler et al., 2020). Amornvit investigated the accuracy of 10 commercially available scanners and observed that trueness varied, although precision was similar for all the scanners. The Trios scanner demonstrated the best results among other scanners (Amornvit et al., 2021). Additionally, Nedelcu has reported that the Trios scanner had a higher accuracy than CEREC (Nedelcu et al., 2018). By contrast, one study has reported that the precision of digital impressions obtained by IOS (iTero, Lythos, Trios)

was of lower quality than those from conventional materials and digitalized by extraoral scanners (Duvert et al., 2017). Ender and Kuhr concluded that conventional impression materials provide significantly higher precision than digital impressions (Ender et al., 2016; Kuhr et al., 2016). However, Grunheid and Sfondrini revealed that IOS acquired data as accurately as alginate impressions (Grunheid et al., 2014; Sfondrini et al., 2018). Comparing the IOS models with the cone-beam computed tomography (CBCT) 3D models, the IOS provided statistically and clinically acceptable accuracy for all measurements. Although the CBCT-derived 3D models underestimated lower dental measurements, such measurements were within clinically acceptable limits (San José et al., 2017).

3.3. Reproducibility of IOS

Previous studies have reported satisfactory to excellent reproducibility of IOS compared to in vivo and ex vivo scanning. This difference, if any, was slight or negligible (Duvert et al., 2017; Naidu et al., 2013; Sun et al., 2018). Wiranto et al. have indicated that both IOS and CBCT scanning of alginate impressions are valid, reliable, and reproducible methods to obtain dental measurements for diagnostic purposes (Wiranto et al., 2013). A systematic review conducted by Aragon et al. has demonstrated that inter- and intra-arch measurements from digital models produced from intraoral scans may be reliable and accurate compared to those from conventional impressions (Aragon et al., 2016). A recent systematic review and *meta*-analysis of in vivo studies concluded that the trueness of digital and alginate full-arch impressions was similar, and that both impression techniques demonstrated high precision. The 3D deviation between the digital and alginate impressions was 0.09 mm. The 3D precision of both impression techniques was < 0.1 mm (Kong et al., 2022).

3.4. Scanning time with IOS

A comparison of the time required to obtain full-arch intraoral digital impressions and conventional impressions has been extensively published. These findings are contradictory in nature, with several studies demonstrating that IOS are time-efficient and reduce working time compared with conventional impression techniques (Burhardt et al., 2016; Goracci et al., 2016; Joda et al., 2017; Lee et al., 2013). However, studies have indicated that alginate impressions require less time than digital scans (Burzynski et al., 2018; Grunheid et al., 2014; Mangano et al., 2018).

3.5. Patient comfort with IOS

Patient comfort with digital and traditional impression methods has been evaluated extensively and was significantly better and more comfortable with digital intraoral scanning. Although the scanning time is longer than that of traditional impression methods, digital scanning is preferred by patients because of its ease of use and comfort (Burhardt et al., 2016; Burzynski et al., 2018; Sfondrini et al., 2018; Yuzbasioglu et al., 2014). Factors such as breathing, smell, taste, and gag reflex are controlled with digital impressions (Christensen et al., 2008; Glisic et al., 2019). Elimination of impression materials and trays drastically improves patient comfort (Wismeijer et al., 2014).

3.6. Operator experience with IOS

A significant learning curve has been reported for IOS in dental clinics. Young dentists who are well-attuned to technology can more easily adapt to IOS use than older dentists (Agnini et al., 2015; Lee et al., 2013; Mandelli et al., 2017). Once the learning curve is established, IOS may confer many significant clinical advantages for clinicians (Lawson et al., 2015). Kim et al. have reported that the learning rate of iTero was faster than that of Trios and was not influenced by clinical experience (Kim et al., 2016). Orthodontists indicated IOS as better and more attractive in their practice (Park et al., 2016).

4. Discussion

With technological advancements in dentistry, the branch of orthodontics has also witnessed a huge surge in 3D approaches towards clinical practice management. Study models are the most basic and important prerequisites for diagnosis and treatment planning in any orthodontic case, and they have become digital in the recent decade. This systematic review aimed to process the literature on the accuracy, reproducibility, scanning time, patient comfort, and operator experience of IOS in orthodontics.

The 3D study models should be accurate, reproducible, easy to construct, and cost-effective. The primary feature of an IOS is its accuracy, which results from its trueness and precision. Accuracy is defined as the closeness of the agreement between a measured quantity and the true quantity of a measurand (JCGM 200:2012; ISO 5725–1, 1994). IOS should be able to match reality as closely as possible, that is, have high trueness and not deviate from reality (Imburgia et al., 2017; Ting-Shu et al., 2015). The accuracy of the scans can be identified by overlapping the digital scans with reference scans obtained from industrial machines using powerful cameras and software. The accuracy of IOS depends on the scanner acquisition and processing software (Ahlholm et al., 2018; Chochlidakis et al., 2016). In this systematic review, the literature has demonstrated contradictory results regarding the accuracy of digital scans compared with that of conventional scans (Amornvit et al., 2021; Duvert et al., 2017; Ender et al., 2016; Grunheid et al., 2014; Kuhr et al., 2016; Nedelcu et al., 2018; San José et al., 2017; Sfondrini et al., 2018; Winkler et al., 2020). However, this finding should be interpreted with caution, as technology is being updated and refined rapidly. Recent late-generation scanners have demonstrated very low errors in full-arch impressions (Imburgia et al., 2017). Hence, understanding the advantages and limitations of these IOS before reaching a conclusion is important (Mangano et al., 2017). In terms of reproducibility, IOS have demonstrated excellent results as well as superior efficiency to conventional impression-making methods (Kirschneck et al., 2018; Kong et al., 2022; Naidu et al., 2013; Sun et al., 2013; Wiranto et al 2013; Yuzbasioglu et al., 2014). However, crowding measured by digital models tends to be less than that measured by cast models, and this should be considered during clinical application (Yoon et al., 2018).

Scanning with IOS has been proven to be time-efficient in the long term in various studies. The usual scanning time for

full-arches is 3–5 min which is similar to or greater than that required for conventional impressions (Joda et al., 2017; Mangano et al., 2018). However, with scanning, the laboratory work required post-impression with alginate or rubber base materials can be avoided. Conventional impressions require additional laboratory space, cast pouring, cleaning, and maintenance to obtain physical plaster models. With IOS, digital files can be directly sent via e-mail to the technical laboratory and processed further. This saves considerable time and money spent on consumables during each clinical year (Joda et al., 2015; Patzelt et al., 2014).

The ability of IOS to capture intraoral details without making physical impressions is one of the main advantages of their clinical applications. The misfit of impression trays, time and resources for cleaning and sterilization, smell and taste of impression material, gag reflex, and apprehension in pediatric patients can all be avoided with digital scanning (Burhardt et al., 2016; Grunheid et al., 2014; Yuzbasioglu et al., 2014). When patients can see their digital impressions on the screen, they can be more involved in the treatment. This helps to explain the treatment plan better, which further increases emotional involvement and treatment compliance (Lim et al., 2017). Thus, IOS can act as a powerful indirect marketing and advertisement tool, as they are welcomed by patients and add value to clinics.

The use of IOS can be complex and perplexing in the beginning; however, once the learning curve is overcome, handling the scanner and software becomes fun and easy. A real-time assessment of impression quality can be performed by an orthodontist and a technician. Missing or less-refined details can be easily recaptured using the scanner. This strengthens the compatibility between orthodontists and technicians (Lecocq et al., 2016; Park et al., 2015). However, no consensus on the specific scanning strategies has been established. Different scanners and techniques produce different results (Mangano et al., 2017). Moreover, the cost of purchasing and managing an IOS may be excessively high for individuals and new practitioners. Thus, this aspect must be considered before entering this segment of practice (Aragón et al., 2016; Imburgia et al., 2017).

This review provides clinicians with a comprehensive understanding of various clinical aspects of IOS scanners in orthodontic practice. As technology becomes new and updated, older published results become less relevant, and readers should focus on recent literature to decide on purchasing a scanner. This is the era of digital orthodontics, and IOS may soon become a basic component of regular practice worldwide. By fabricating accurate orthodontic appliances for printing aligners, practical applications of IOS will increase rapidly in the future. Further research using different scanners on different cases with different strategies is recommended.

5. Conclusion

Digital impressions may not be as accurate as conventional impressions, although the use of IOS is clinically acceptable for orthodontic treatment planning, appliances, and aligner fabrication in Orthodontics. Scanning time with IOS is higher than that with the conventional impression; however, IOS are time-efficient and simple, and they eliminate laboratory plaster work. Patient comfort is undoubtedly better with IOS than with the conventional methods. Although the operator/orthodontist must overcome a learning curve to become accustomed to IOS equipment and software, operators/orthodontists have reported IOS to be easier, more attractive, and comfortable to use in practice.

CRediT authorship contribution statement

Ahmed Mohammed Alassiry: Conceptualization, Methodology, Data curation, Writing – original draft.

References

Agnini, A., Agnini, A., Coachman, C., 2015. The Digital Revolution: The Learning Curve. Quintessence Publishing.

Ahlholm, P., Sipilä, K., Vallittu, P., Jakonen, M., Kotiranta, U., 2018. Digital versus conventional impressions in fixed prosthodontics: a review. J. Prosthodont. 27 (1), 35–41.

Amornvit, P., Rokaya, D., Sanohkan, S., 2021. Comparison of accuracy of current ten intraoral scanners. Biomed. Res. Int. 13 (2021), 2673040.

Aragón, M.L., Pontes, L.F., Bichara, L.M., Flores-Mir, C., Normando, D., 2016. Validity and reliability of intraoral scanners compared to conventional gypsum models measurements: a systematic review. Eur. J. Orthod. 38 (4), 429–434.

Burhardt, L., Livas, C., Kerdijk, W., van der Meer, W.J., Ren, Y., 2016. Treatment comfort, time perception, and preference for conventional and digital impression techniques: a comparative study in young patients. Am. J. Orthod. Dentofac. Orthop. 150 (2), 261–267.

Burzynski, J.A., Firestone, A.R., Beck, F.M., Fields Jr, H.W., Deguchi, T., 2018. Comparison of digital intraoral scanners and alginate impressions: time and patient satisfaction. Am. J. Orthod. Dentofacial Orthop. 153 (4), 534–541.

Chochlidakis, K.M., Papaspyridakos, P., Geminiani, A., Chen, C.J., Feng, I.J., Ercoli, C., 2016. Digital versus conventional impressions for fixed prosthodontics: a systematic review and meta-analysis. J. Prosthet. Dent. 116 (2), 184–190.e12.

Christensen, G.J.G.J., 2008. Will digital impressions eliminate the current problems with conventional impressions? J. Am. Dent. Assoc. 139 (6), 761–763.

Duvert, R., Gebeile-Chauty, S., 2017. Is the precision of intraoral digital impressions in orthodontics enough? Orthod. Fr. 88 (4), 347–354.

Ender, A., Attin, T., Mehl, A., 2016. In vivo precision of conventional and digital methods of obtaining complete-arch dental impressions. J. Prosthet. Dent. 115 (3), 313–320.

Ender, A., Mehl, A., 2013. Accuracy of complete-arch dental impressions: a new method of measuring trueness and precision. J. Prosthet. Dent. 109 (2), 121–128.

Glisic, O., Hoejbjerre, L., Sonnesen, L., 2019. A comparison of patient experience, chair-side time, accuracy of dental arch measurements and costs of acquisition of dental models. Angle Orthod. 89 (6), 868–875. https://doi.org/10.2319/020619-84.1.

Goracci, C., Franchi, L., Vichi, A., Ferrari, M., 2016. Accuracy, reliability, and efficiency of intraoral scanners for full-arch impressions: a systematic review of the clinical evidence. Eur. J. Orthod. 38 (4), 422–428.

Grünheid, T., McCarthy, S.D., Larson, B.E., 2014. Clinical use of a direct chairside oral scanner: an assessment of accuracy, time, and patient acceptance. Am. J. Orthod. Dentofacial Orthop. 146 (5), 673–682.

Hajeer, M.Y., Millett, D.T., 2004. Applications of 3D imaging in orthodontics: part I. J. Orthod. 31, 62–70.

Harrell, E.R., 2018. An evidence-based evaluation of three-dimensional scanning technology in orthodontic practice. Decis. Dent. 4, 17–20.

Imburgia, M., Logozzo, S., Hauschild, U., Veronesi, G., Mangano, C., Mangano, F.G., 2017. Accuracy of four intraoral scanners in oral implantology: a comparative in vitro study. BMC Oral Health 17 (1), 92.

Joda, T., Bragger, U., 2015. Digital vs. conventional implant prosthetic workflows: a cost/time analysis. Clin. Oral Implants Res. 26 (12), 1430–1435.

Joda, T., Lenherr, P., Dedem, P., Kovaltschuk, I., Bragger, U., Zitzmann, N.U., 2017. Time efficiency, difficulty, and operator's preference comparing digital and conventional implant impressions: a randomized controlled trial. Clin. Oral Implants Res. 28 (10), 1318–1323.

Kim, J., Park, J.M., Kim, M., Heo, S.J., Shin, I.H., Kim, M., 2016. Comparison of experience curves between two 3-dimensional intraoral scanners. J. Prosthet. Dent. 116 (2), 221–230.

Kirschneck, C., Kamuf, B., Putsch, C., Chhatwani, S., Bizhang, M., Danesh, G., 2018. Conformity, reliability and validity of digital dental models created by clinical intraoral scanning and extraoral plaster model digitization workflows. Comput. Biol. Med. 1 (100), 114–122.

Kong, L., Li, Y., Liu, Z., 2022. Digital versus conventional full-arch impressions in linear and 3D accuracy: a systematic review and meta-analysis of in vivo studies. Clin. Oral Investig. 26 (9), 5625–5642.

Kuhr, F., Schmidt, A., Rehmann, P., Wöstmann, B., 2016. A new method for assessing the accuracy of full arch impressions in patients. J. Dent. 55, 68–74.

Lawson, N.C., Burgess, J.O., 2015. Clinicians reaping benefits of new concepts in impressioning. Compend. Contin. Educ. Dent. 36 (2), 152–153.

Lecocq, G., 2016. Digital impression-taking: fundamentals and benefits in orthodontics. Int. Orthod. 14 (2), 184–194.

Lee, S.J., Gallucci, G.O., 2013. Digital vs. conventional implant impressions: efficiency outcomes. Clin. Oral Implants Res. 24 (1), 111–115.

Lee, S.J., Macarthur 4th, R.X., Gallucci, G.O., 2013. An evaluation of student and clinician perception of digital and conventional implant impressions. J. Prosthet. Dent. 110 (5), 420–423.

Lim JH, Park JM, Kim M, Heo SJ, Myung JY. Comparison of digital intraoral scanner reproducibility and image trueness considering repetitive experience. J Prosthet Dent. 2017 Jul 7. pii: S0022–3913 (17)30350–5

Logozzo S, Franceschini G, Kilpela A, Caponi M, Governi L, Blois L. A comparative analysis of intraoral 3D digital scanners for restorative dentistry. Int J Med Tech. 2011. https:// doi. org/ 10. 5580/ 1b90.

Logozzo, S., Zanetti, E.M., Franceschini, G., Kilpela, A., Makynen, A., 2014. Recent advances in dental optics—part I: 3D intraoral scanners for restorative dentistry. Optic. Lasers Eng. 54 (3), 203–221.

Mandelli, F., Ferrini, F., Gastaldi, G., Gherlone, E., Ferrari, M., 2017. Improvement of a digital impression with conventional materials: overcoming intraoral scanner limitations. Int. J. Prosthodont. 30 (4), 373–376.

Mangano, A., Beretta, M., Luongo, G., Mangano, C., Mangano, F., 2018. Conventional vs digital impressions: acceptability, treatment comfort and stress among young orthodontic patients. Open Dent. J. 31 (12), 118–124.

Mangano, F., Gandolfi, A., Luongo, G., Logozzo, S., 2017. Intraoral scanners in dentistry: a review of the current literature. BMC Oral Health 17 (1), 149.

Marcel, T., 2001. Three-dimensional on-screen virtual models. Am. J. Orthod. Dentofacial Orthop. 119, 666–668.

Martin, C.B., Chalmers, E.V., McIntyre, G.T., Cochrane, H., Mossey, P.A., 2015. Orthodontic scanners: what's available? J. Orthod. 42 (2), 136–143.

Moher, D., Liberati, A., Tetzlaff, J., Altman, D.G., 2009. The PRISMA Group: preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med. 6 (7), e1000097.

Morris, J.B., 2010. CAD/CAM options in dental implant treatment planning. J. Calif. Dent. Assoc. 38, 333–336.

Naidu, D., Freer, T.J., 2013. Validity, reliability, and reproducibility of the iOC intraoral scanner: a comparison of tooth widths and Bolton ratios. Am. J. Orthod. Dentofacial Orthop. 144 (2), 304–310.

Nedelcu, R., Olsson, P., Nyström, I., Rydén, J., Thor, A., 2018. Accuracy and precision of 3 intraoral scanners and accuracy of conventional impressions: a novel in vivo analysis method. J. Dent. 69, 110–118.

Park, J.H., Laslovich, J., 2016. Trends in the use of digital study models and other technologies among practicing orthodontists. J. Clin. Orthod. 50 (7), 413–419.

Park, H.R., Park, J.M., Chun, Y.S., Lee, K.N., Kim, M., 2015. Changes in views on digital intraoral scanners among dental hygienists after training in digital impression taking. BMC Oral Health 15 (1), 151.

Patzelt, S.B., Lamprinos, C., Stampf, S., Att, W., 2014. The time efficiency of intraoral scanners: an in vitro comparative study. J. Am. Dent. Assoc. 145 (6), 542–551.

San José V, Bellot-Arcís C, Tarazona B, Zamora N, O Lagravère M, Paredes-Gallardo V. Dental measurements and Bolton index reliability and accuracy obtained from 2D digital, 3D segmented CBCT, and 3d intraoral laser scanner. J Clin Exp Dent. 2017 Dec 1;9(12):e1466-e1473

Sfondrini, M.F., Gandini, P., Malfatto, M., Di Corato, F., Trovati, F., Scribante, A., 2018. Computerized casts for orthodontic purpose using powder-free intraoral scanners: accuracy, execution time, and patient feedback. Biomed. Res. Int. 23 (2018), 4103232.

Sun, L., Lee, J.S., Choo, H.H., Hwang, H.S., Lee, K.M., 2018. Reproducibility of an intraoral scanner: a comparison between in-vivo and ex-vivo scans. Am. J. Orthod. Dentofacial Orthop. 154 (2), 305–310.

Ting-Shu, S., Jian, S., 2015. Intraoral digital impression technique: a review. J. Prosthodont. 24 (4), 313–321.

Winkler, J., Gkantidis, N., 2020. Trueness and precision of intraoral scanners in the maxillary dental arch: an in vivo analysis. Sci. Rep. 10 (1), 1172.

Wiranto, M.G., Engelbrecht, W.P., Tutein Nolthenius, H.E., van der Meer, W.J., Ren, Y., 2013. Validity, reliability, and reproducibility of linear measurements on digital models obtained from intraoral and cone-beam computed tomography scans of alginate impressions. Am. J. Orthod. Dentofacial Orthop. 143 (1), 140–147.

Wismeijer, D., Mans, R., van Genuchten, M., Reijers, H.A., 2014. Patients' preferences when comparing analogue implant impressions using a polyether impression material versus digital impressions (Intraoral Scan) of dental implants. Clin. Oral Implants Res. 25 (10), 1113–1118.

Yoon JH, Yu HS, Choi Y, Choi TH, Choi SH, Cha JY. Model Analysis of Digital Models in Moderate to Severe Crowding: In Vivo Validation and Clinical Application. Biomed Res Int. 2018 Jan 14;2018:8414605.

Yuzbasioglu, E., Kurt, H., Turunc, R., Bilir, H., 2014. Comparison of digital and conventional impression techniques: evaluation of patients' perception, treatment comfort, effectiveness and clinical outcomes. BMC Oral Health 30 (14), 10.

Zimmermann, M., Mehl, A., Mörmann, W.H., Reich, S., 2015. Intraoral scanning systems – a current overview. Int. J. Comput. Dent. 18 (2), 101–129.