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The trueness of an intraoral scanner in scanning different post space depths

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ABSTRACT

Objectives: The purpose of this in vitro study was to evaluate the trueness of scanning the post space up to 20 mm with an intraoral scanner (IOS).
Methods: We captured 20-, 18-, 16-, 14-, 12-, and 10-mm length post space scans using an IOS (Primescan) eight times each by shortening the apical 2 mm end of the same mandibular canine tooth. The reference impressions of each length group were taken using a light-body polyvinyl siloxane impression material and were scanned with an extraoral scanner. The recorded standard tessellation language (STL) data of all impressions were uploaded to a 3D matching program for the trueness evaluation via the root mean square (RMS) calculation. For the statistical analysis, the Kruskal-Wallis and post-hoc Mann-Whitney U nonparametric tests were performed to compare the differences among the groups (α=0.05).
Results: The median RMS values increased in direct proportion to the length of the post space from 10 mm (357.1 μm) to 20 mm (897.5 μm). We noted a significant difference among groups ($p< 0.001$). In the pairwise comparisons, there were no significant differences between the 14 mm and 16 mm groups (p=0.431) or between the 18 mm and 20 mm groups (p=0.036), while other paired groups showed significant differences (p=0.001).
Conclusions: The scanned space depth affected the trueness of the IOS (Primescan). If the post depth was below 14 mm, and the minimum diameter was 2.2 mm, Primescan could be used for impressions of the post-core structure, simplifying the impression procedure.
Clinical significance: IOS seems to be a promising technology for taking digital impressions of post spaces, but cannot be recommended as a routine procedure at its present stage, as final results are highly dependent on the clinical situation. Further studies with different IOS systems are needed to gain sound evidence.

1. Introduction

Digitalization has brought many conveniences to dentistry, such as saving chair time, standardization, and precision in treatment steps. In clinical practice, a digital restorative workflow begins with a digital impression provided by an intraoral scanner (IOS). There are many different commercially available IOSs in the dental market, and their limitations have gradually decreased as manufacturers have found solutions to address various kinds of clinical needs [1]. In the early days of dental digitalization, the use of IOSs was limited to single crown and inlay/onlay restoration scans [2]; however, it has since become possible to scan both soft and hard dental tissues for every type of restoration [1].

Customized cast posts manufactured from gold alloys have been regarded as the “gold standard” for this procedure [3]; however, prefabricated esthetic post alternatives to custom casts have been developed for enhanced esthetics, lower root fracture rates, and ease of application [4]. Recently, prefabricated fiber-reinforced composite (FRC) posts have emerged as the most-preferred system. FRC posts' stress distribution to the root and neighboring tissues is uniform due to their similar elasticity with dentin, decreasing the risk of root fracture [4,5]. Additionally, they allow for a single-visit application and lead to a satisfactory esthetic outcome [4]. Despite these benefits, the adaptation of prefabricated circular post systems for root canals is limited if the root canal's shape is ovoid [6]. To enhance the adaptation of the post to the root canal, oval-shaped fiber posts have been produced for oval-shaped canals, but some studies have reported higher cement thickness around oval fiber posts than around circular ones [7,8]. Further, the post shape affects the stress distribution between the post and the mandibular premolar root dentin, so circular fiber posts bring about greater stress than oval fiber posts [9].

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Custom posts fabricated from an advanced current resin composite or hybrid materials with an elastic modulus and shade close to the dentin could be a good alternative for eliminating most of the mechanical and esthetic risk factors of prefabricated post systems [10]. It is essential to preserve tooth structure and not to remove excessive root dentin when adapting the chosen post system. Accordingly, customized fabrication of a post eliminates the excessive removal of the root dentin, and an anatomically fitted post can be manufactured at the appropriate length. [11]. Recently, a new IOS has been produced that claims to allow taking impressions of the prepared post space, as its scanner's depth has been reported as up to 20 mm [12]. Although depth scans of cavity preparations up to 5 mm were investigated in a previous study, there is a lack of studies in the literature evaluating the scanning ability of the IOSs for deeper areas, even though these are necessary, especially for post space scans [13].

The purpose of the present in vitro study was to evaluate the trueness of scanning the post spaces of different lengths up to 20 mm using an IOS. The trueness of the measure was detected by evaluating the degree of deviation from the exact value [14]. Root mean square (RMS) values are often used to reach trueness evaluations; a low RMS value indicates high trueness [13,15].

The null hypothesis was that no significant differences would be found among the scanning trueness of post spaces of different lengths.

2. Material and methods

A caries-free human mandibular canine tooth that was extracted for periodontal reasons was used in the study. This study was approved by the Non-Interventional Clinical Research Ethical Committee of Istanbul Okan University (05.05.2021/137). The tooth had a sufficient root length of 18 mm and a crown length of 10 mm, allowing for a maximum post space preparation of 20 mm (Fig. 1A). The test groups were designed as 20-, 18-, 16-, 14-, 12-, and 10-mm length post spaces, each of which was scanned eight times. The root of the extracted tooth was cleaned of all residual soft tissue with a scaler, and 0.1% thymol solution was used as a storage medium for 48 hours. The coronal part of the tooth was sectioned 3 mm above the cement–enamel junction with a double-sided diamond disc, and a crown preparation with a 3 mm ferrule and a 1 mm-wide margin was handled with a 1 mm-wide diamond chamfer bur. The root canal access cavity was prepared carefully without causing undercut areas, and the root canal was instrumented using rotary files (Protaper Next, Dentsply Sirona) using an endodontic motor (VDW.Gold Reciproc, VDW, Munich, Germany) (Fig. 1B, C).

The apical 1 mm of the root was obturated with a gutta-percha cone (Diadent; Chongju, Korea). For the post space preparation, post drills (Cytec; Hahnenkratt, Germany) with 1.4 mm (yellow), 1.8 mm (blue), and 2.2 mm (black) diameters were used according to the manufacturer's instructions. The scanning depth was 20 mm with the coronal and root parts. The space length was checked with a rotary file adjusted to 20 mm via a rubber stopper (Fig. 2)

The prepared tooth was embedded in pink-shaded cold-curing methyl methacrylate resin (S.C.; Imıcryl, Turkey) with the cement-enamel junction as the top surface (Fig. 3A). The conventional post space impression was taken with a light-body polyvinyl siloxane impression material (Hydrorise light body, Zhermack, Italy) with the aid of a wooden toothpick prepared according to the space's length and width to support the silicone material and prevent dimensional changes in the impression during removing. Firstly, with a 40no Lentulo spiral (VDW; Munich, Germany), some of the impression material was inserted into the prepared space, and then the wooden toothpick was stabilized in its center until the material polymerized. With the aid of the stick, the impression was pulled out of the post space. The post space impression length was checked with a rotary file adjusted to 20 mm (Fig. 3B). The silicone impression was scanned with an extraoral scanner (CEREC inEos X5; Dentsply Sirona; Bensheim, Germany), and the standard tessellation language (STL) data was recorded as a reference for the 20 mm length group.

A priori power analysis was performed considering the Primescan measurement values of a previous study [13] using the G*Power power analysis software (v.3.1.9.4). The minimum group sample size was determined to be 2 (power=0.95; effect size=2.24), and a group sample size of 8 was used to increase the study's power.

The tooth with the prepared post space was scanned with an IOS (CEREC Primescan 5.0.0; Dentsply Sirona; Bensheim, Germany) eight times by the same investigator, and the data were recorded. The same tooth was used for all groups by shortening the root length accordingly. The tooth was stored in 4°C distilled water to avoid dehydration between processes.

For the 18 mm post space preparation, the 2 mm apical portion of the root was sectioned, and the apical 1 mm of the remaining root was obturated with a gutta-percha cone (Diadent; Chongju, Korea). The total space length was checked with a rotary file adjusted to 18 mm via a rubber stopper (MANI; Kıyohara, Japan). The reference impression and tested data were obtained using the same methods as the 20 mm length

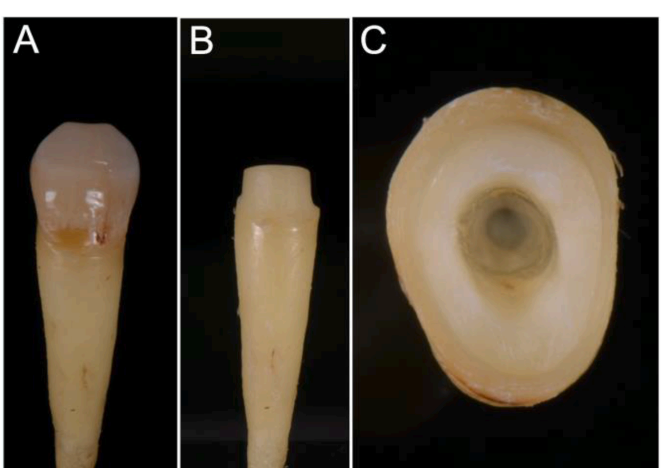

Fig. 1. A. Image of the selected mandibular canine tooth for the study; B. Frontal view of the prepared tooth; C. Occlusal view of the prepared post space.

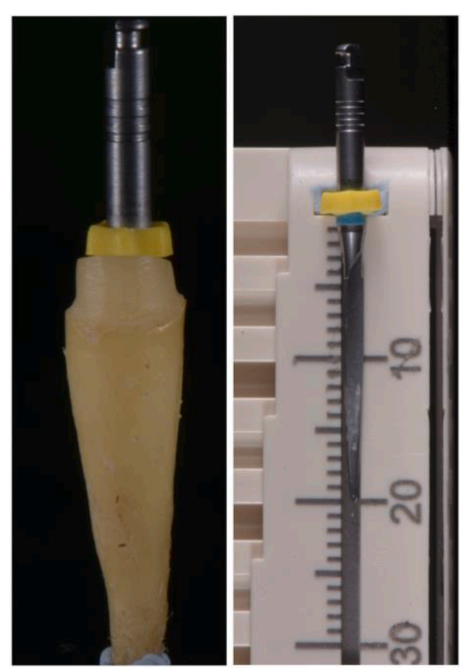

Fig. 2. Depth check of the prepared 20 mm post space.

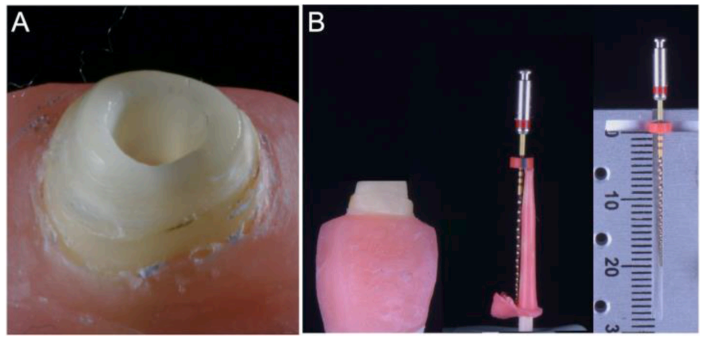

Fig. 3. A. The image of the embedded tooth in pink-shaded cold-curing methyl methacrylate resin; B. Length check of the silicone impression for the 20 mm post space.

group. The same procedures were repeated for 16-, 14-, 12-, and 10-mm test groups (Fig. 4A, B), and the data were recorded.

The recorded impression data were saved as STL files to be compatible with the 3D matching program (Geomagic Control X 2020; 3D Systems; Rock Hill, SC, USA). The extraoral scans of each length were trimmed from the post space entrance only to match the post space impressions. For each length group, the trimmed extraoral scans were uploaded as "reference data," and the intraoral scans were uploaded as "measured data." "Initial alignment," "best-fit alignment," and "3D compare" steps were used to evaluate the 3D comparison. Discrepancies between the reference and measured data were calculated as the root mean square (RMS) values and recorded for the trueness evaluation [13, 15]. The software automatically calculated the values, and the data were recorded for statistical analyses. A lower RMS value indicates higher trueness. A color map representing visual deviation [16,17] in the region outside this range was used: red-yellow colors indicated a positive deviation, and blue-turquoise colors indicated a negative deviation.

Statistical analyses were performed using the PASW Statistics software v.18.0 (SPSS Inc; Chicago, IL, USA). The RMS data were assessed for normality and homogeneity using the Shapiro–Wilk and Levene tests, respectively. The Kruskal–Wallis and posthoc Mann–Whitney U nonparametric tests were used to identify group differences. The type 1 error risk was controlled with a Bonferroni correction accounting for the number of comparisons with a significance level of $\alpha = 0.05$. After Bonferroni correction, we used a significance level of 0.003 (0.05/15).

3. Results

The median and first and third quartile RMS values for each post space depth are presented in Table 1. As post depth increased, RMS values also increased. The Kruskal–Wallis test indicated RMS differed significantly between groups ($p < 0.001$). In the pairwise comparisons, RMS did not differ significantly between the 14 mm and 16 mm groups ($p = 0.431$) and 18 mm and 20 mm groups ($p = 0.036$). However, RMS differed significantly between all other group pairs ($p = 0.001$). Fig. 5 shows a boxplot of RMS for each post space length. Deviations were primarily seen in the apical region of the post space, particularly at the cavity's base, in all groups (Fig. 6).

Table 1
Median, first (Q1) and third (Q3) quartile values of each post space length (μm).

Group	Median	Q1	Q3
10 mm	357.1	353.1	366
12 mm	419.6	401.2	435
14 mm	502.6	494.3	512.9
16 mm	528.3	454.6	542.9
18 mm	856.2	844.3	887.1
20 mm	897.5	868	921.5

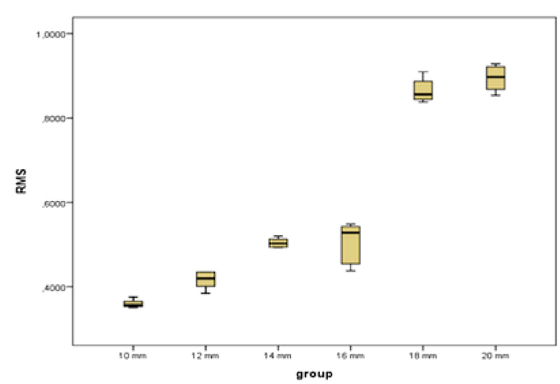

Fig. 5. RMS values of each group.

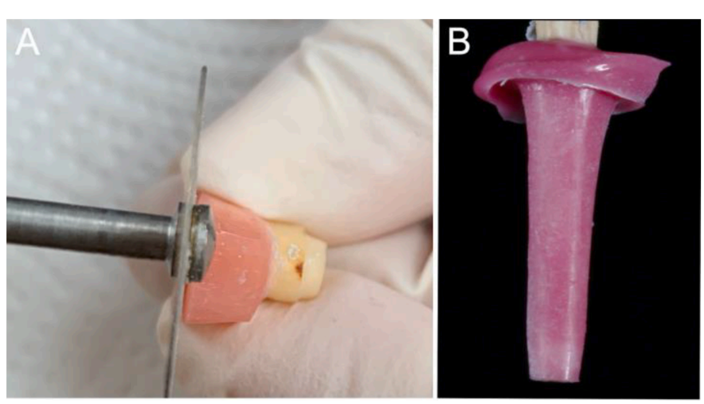

Fig. 4. A. A representative image for shortening the apical 2 mm of the embedded tooth; B. A representative image of silicone impression of the shortened post space.

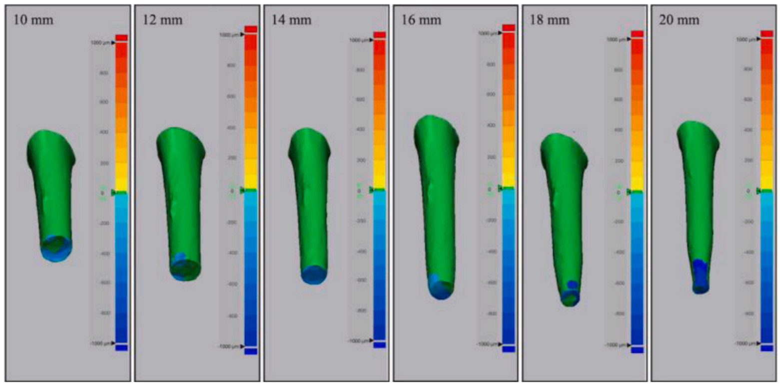

Fig. 6. Representative color map images for deviation distribution pattern of each group. Blue represents negative deviation of reference file and green represents deviation within range of nominal values. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

4. Discussion

This study's null hypothesis was rejected because post space length affected the trueness of intraoral scans, and significant differences were found between the RMS values of post space scans with different heights.

The complexity of post space impressions and the need for another session for laboratory procedures [18] has increased the popularity of prefabricated fiber posts [4,19]. Grandini et al. [20] found that poor prefabricated post adaptation increased the cement thickness, resulting in a greater risk of voids and bubbles in the cement layer, which might decrease luting material strength. Fernandes et al. [21] similarly found that custom posts provide better adaptation, reducing cement thickness, concluding that decreased cement thickness reduced the possibility of pores, cracks, or gaps within the cement layer, which might cause mechanical failure at the interface.

A perfect impression is necessary for a precise adaptation of customized post systems. Many studies have found that it is possible to achieve better adaptation of crown restorations with IOSs rather than analog techniques [15,22–24]. The post's adaptation to the prepared post space and cement thickness has been studied previously [25–28]. A cement thickness of 250–500 µm was found to be clinically acceptable [28]. In this study, post space length <14 mm showed RMS values <500 µm, which might be considered acceptable in clinical practice. Based on the radiographic control image, the dentist can measure the length of the prospective post and then decide whether to use the IOS system based on that measurement.

Pinto et al. [29] evaluated post-depth scanning of an IOS (3Shape Trios 3) compared to a traditional silicone impression taken with a plastic post and a custom tray. The post spaces were prepared on decoronated premolar teeth, and the prepared depths were between 8.5 and 9.8 mm. The preparations were 1 mm above the cement-enamel junction to the apical part of the post space, and no ferrule was structured. In this study, the mandibular canine tooth was used, and the shortest post space prepared was 10 mm, including a 3 mm coronal ferrule height in addition to root space. When post space depth was <10 mm, Pinto et al. [29] found that the 3 Shape IOS scanning efficiency was inadequate for post space impression, particularly for narrow root channels.

In this study, the ferrule preparation was handled 3 mm above the cement-enamel junction to mimic clinical conditions, creating a larger entrance and possibly making it easier to scan the post space, even for deeper spaces. There have been numerous IOSs on the dental market. However, scanning ability at depths greater than 10 mm was claimed only for Primescan. In 2019, the CEREC Company announced that it was possible to scan deep spaces ≤20 mm with Primescan [12], enabling scans of long post spaces and fabrication of customized posts from CAD/CAM materials. This study was designed to test the scanning ability of IOS at post space depths >10 mm. Therefore, only Primescan was included in this study, and the maximum post space length prepared was 20 mm, which is more common in canine teeth with long roots.

The results of this study showed that the median RMS values increased with post space lengths from 10 mm (357.1 µm) to 20 mm (897.5 µm). Few studies have assessed the IOSs' depth scanning efficiency for intracoronal restorations. Gurpinar and Tak [13] examined the accuracy of six different IOSs on scanning 2, 3.5, and 5 mm deep endocrown preparations. The CEREC Primescan showed the greatest accuracy of all IOSs. However, significant differences were found in the scanning trueness of endocrown preparation depths independent of the scanner. The trueness of the scans increased with decreasing depths, supporting this study's findings. Shin et al. [30] evaluated the marginal and internal discrepancies of endocrown restorations with 2 and 4 mm cavity depths prepared on human molars. Two scanners, CEREC AC Bluecam and Planmeca E4D, were used for digital cavity impressions. They similarly found that discrepancies increased with deeper cavity preparations.

Park et al. [31] found that restoration cavity shape also affected the trueness of intraoral scans, with higher deviation values for cavities with more complex shapes. In this study, to eliminate scan differences due to differences in cavity shape, length, and width, the same tooth was used by shortening it 2 mm from the apical ending for each group. However, post space cavity gets narrower apically. The narrowest apical ending was seen at the longest post space and showed the lowest trueness (897.5 µm). In addition to the deepness of the scanned space, the narrowing configuration might cause high deviation values with increasing post space length.

The use of extraoral scanners as a reference has been reported in several studies [32–35], and, similar to this study, an extraoral scanner (CEREC InEOS X5) with high trueness [36] was used as a reference scanner. The reference scan was compared with the IOS scans and analyzed with the aid of color-coded maps showing deviation patterns. Studies evaluating scan accuracy used similar color-coded maps in their comparisons [13,31].

This study had some limitations. The results were acquired with digital scans of the specimens in a non-clinical environment, which did not recreate intraoral conditions such as saliva contamination, patient movements, and light reflections of intraoral structures. The width of the post space entrance was standardized. However, deviations may be different for different shaped post spaces since lighting will differ. Another limitation was that only one IOS was used, and only trueness measures were performed. Further studies are needed to assess the scanning capabilities of different IOS systems for different post space configurations.

5. Conclusions

The following conclusions can be drawn from this study within its limitations:

1 Scanned space depth affected the trueness of IOS (Primescan) scans.
2 When the prepared overall post space depth is >14 mm, the adaptation of the custom post-core structure will be inadequate, resulting in increased cement thickness.
3 When the prepared overall post space depth is <14 mm and the diameter is > 2.2 mm, Primescan (IOS) can be considered for the post-core structure impression, simplifying the impression procedures.

CRediT authorship contribution statement

Bahar Elter: Methodology, Investigation, Writing – original draft. **Burcu Diker:** Data curation. **Önjen Tak:** Methodology.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] T.F. Alghazzawi, Advancements in CAD/CAM technology: Options for practical implementation, J. Prosthodont. Res. 60 (2016) 72–84, https://doi.org/10.1016/j.jpor.2016.01.003.
[2] F. Duret, J.-L. Blouin, B. Duret, CAD-CAM in dentistry, J. Am. Dent. Assoc. 117 (1988) 715–720, https://doi.org/10.14219/jada.archive.1988.0096.
[3] B. Bergman, P. Lundquist, U. Sjögren, G. Sundquist, Restorative and endodontic results after treatment with cast posts and cores, J. Prosthet. Dent. 61 (1989) 10–15, https://doi.org/10.1016/0022-3913(89)90099-1.
[4] C. Goracci, M. Ferrari, Current perspectives on post systems: a literature review, Aust. Dent. J. 56 (Suppl 1) (2011) 77–83, https://doi.org/10.1111/j.1834-7819.2010.01298.x.
[5] G. Bateman, D.N.J. Ricketts, W.P. Saunders, Fibre-based post systems: a review, Br. Dent. J. 195 (2003) 43–48, https://doi.org/10.1038/sj.bdj.4810278, discussion 37.
[6] I. Coniglio, F. Garcia-Godoy, E. Magni, C.A. Carvalho, M. Ferrari, Resin cement thickness in oval-shaped canals: oval vs. circular fiber posts in combination with different tips/drills for post space preparation, Am. J. Dent. 22 (2009) 290–294.
[7] Ö. Er, K. Kılıç, H.İ. Kılınç, T. Aslan, B. Sağsen, Evaluation of the resin cement thicknesses and push-out bond strengths of circular and oval fiber posts in oval-shapes canals, J. Adv. Prosthodont. 7 (2015) 15–20, https://doi.org/10.4047/jap.2015.7.1.15.
[8] C. Rengo, G. Spagnuolo, G. Ametrano, J. Juloski, S. Rengo, M. Ferrari, Micro-computerized tomographic analysis of premolars restored with oval and circular posts, Clin. Oral Investig. 18 (2014) 571–578, https://doi.org/10.1007/s00784-013-0982-7.
[9] O. Er, K. Kilic, E. Esim, T. Aslan, H.I. Kilinc, S. Yildirim, Stress distribution of oval and circular fiber posts in amandibular premolar: a three-dimensional finite element analysis, J. Adv. Prosthodont. 5 (2013) 434–439, https://doi.org/10.4047/jap.2013.5.4.434.
[10] A. Fadag, M. Negm, A. Samran, A. Samran, G. Ahmed, A. Alqerban, M. Özcan, Fracture Resistance of Endodontically Treated Anterior Teeth Restored with Different Post Systems: An In Vitro Study, Eur. Endod. J. 3 (2018) 174–178, https://doi.org/10.14744/eej.2018.70299.
[11] R.D. Trushkowsky, Restoration of endodontically treated teeth: criteria and technique considerations, Quintessence Int 45 (2014) 557–567, https://doi.org/10.3290/j.qi.a31964.
[12] Primescan | Dentsply Sirona Asia Pacific, (n.d.). https://www.dentsplysirona.com/en-hk/categories/cerec/cerec-primescan.html.
[13] B. Gurpinar, O. Tak, Effect of pulp chamber depth on the accuracy of endocrown scans made with different intraoral scanners versus an industrial scanner: An in vitro study, J. Prosthet. Dent. (2020), https://doi.org/10.1016/j.prosdent.2020.08.034.
[14] No Title, ISO 5725-1 Accuracy (Trueness Precision) Meas, Methods Results Part 1 Gen. Princ. Defin. (1994).
[15] X. Yang, P. Lv, Y. Liu, W. Si, H. Feng, Accuracy of Digital Impressions and Fitness of Single Crowns Based on Digital Impressions, Mater. (Basel, Switzerland). 8 (2015) 3945–3957, https://doi.org/10.3390/ma8073945.
[16] J.B. Carbajal Mejía, K. Wakabayashi, T. Nakamura, H. Yatani, Influence of abutment tooth geometry on the accuracy of conventional and digital methods of obtaining dental impressions, J. Prosthet. Dent. 118 (2017) 392–399, https://doi.org/10.1016/j.prosdent.2016.10.021.
[17] J.Y. Sim, Y. Jang, W.C. Kim, H.Y. Kim, D.H. Lee, J.H. Kim, Comparing the accuracy (trueness and precision) of models of fixed dental prostheses fabricated by digital and conventional workflows, J. Prosthodont. Res. 63 (2019) 25–30, https://doi.org/10.1016/J.JPOR.2018.02.002.
[18] A.P. de Moraes, V. Poletto Neto, N. Boscato, T. Pereira-Cenci, Randomized clinical trial of the influence of impression technique on the fabrication of cast metal posts, J. Prosthet. Dent. 116 (2016) 47–51, https://doi.org/10.1016/j.prosdent.2015.11.022.
[19] I. Dikbas, J. Tanalp, An overview of clinical studies on fiber post systems, ScientificWorldJournal 2013 (2013), 171380, https://doi.org/10.1155/2013/171380.
[20] S. Grandini, C. Goracci, F. Monticelli, A. Borracchini, M. Ferrari, SEM evaluation of the cement layer thickness after luting two different posts, J. Adhes. Dent. 7 (2005) 235–240.
[21] V. Fernandes, A.S. Silva, O. Carvalho, B. Henriques, F.S. Silva, M. Özcan, J.C. M. Souza, The resin-matrix cement layer thickness resultant from the intracanal fitting of teeth root canal posts: an integrative review, Clin. Oral Investig. 25 (2021) 5595–5612, https://doi.org/10.1007/s00784-021-04070-9.
[22] F. Ferrini, G. Sannino, C. Chiola, P. Capparé, G. Gastaldi, E.F. Gherlone, Influence of Intra-Oral Scanner (I.O.S.) on The Marginal Accuracy of CAD/CAM Single Crowns, Int. J. Environ. Res. Public Health. 16 (2019), https://doi.org/10.3390/ijerph16040544.
[23] K.M. Chochlidakis, P. Papaspyridakos, A. Geminiani, C.-J. Chen, I.J. Feng, C. Ercoli, Digital versus conventional impressions for fixed prosthodontics: A systematic review and meta-analysis, J. Prosthet. Dent. 116 (2016) 184–190, https://doi.org/10.1016/j.prosdent.2015.12.017, e12.
[24] J. Vág, Z. Nagy, C. Bocklet, T. Kiss, Á. Nagy, B. Simon, Á. Mikolicz, W. Renne, Marginal and internal fit of full ceramic crowns milled using CADCAM systems on cadaver full arch scans, BMC Oral Health 20 (2020) 189, https://doi.org/10.1186/s12903-020-01181-9.
[25] K. Aleisa, S.R. Habib, A.S. Ansari, R. Altayyar, S. Alharbi, S.A.S. Alanazi, K. T. Alduaiji, Effect of Luting Cement Film Thickness on the Pull-Out Bond Strength of Endodontic Post Systems, Polymers (Basel) 13 (2021) 3082, https://doi.org/10.3390/polym13183082.
[26] D. Dietschi, S. Ardu, A. Rossier-Gerber, I. Krejci, Adaptation of adhesive post and cores to dentin after in vitro occlusal loading: evaluation of post material influence, J. Adhes. Dent. 8 (2006) 409–419.
[27] J. Perdigão, G. Gomes, V. Augusto, The effect of dowel space on the bond strengths of fiber posts, J. Prosthodont. Off. J. Am. Coll. Prosthodont. 16 (2007) 154–164, https://doi.org/10.1111/j.1532-849X.2006.00166.x.
[28] D. Assif, S. Bleicher, Retention of serrated endodontic posts with a composite luting agent: effect of cement thickness, J. Prosthet. Dent. 56 (1986) 689–691, https://doi.org/10.1016/0022-3913(86)90145-9.
[29] A. Pinto, L. Arcuri, P. Carosi, R. Nardi, A. Libonati, L. Ottria, V. Campanella, In vitro evaluation of the post-space depth reading with an intraoral scanner (IOS) compared to a traditional silicon impression, Oral Implantol. (Rome). 10 (2017) 360–368, https://doi.org/10.11138/orl/2017.10.4.360.
[30] Y. Shin, S. Park, J.-W. Park, K.-M. Kim, Y.-B. Park, B.-D. Roh, Evaluation of the marginal and internal discrepancies of CAD-CAM endocrowns with different cavity depths: An in vitro study, J. Prosthet. Dent. 117 (2017) 109–115, https://doi.org/10.1016/j.prosdent.2016.03.025.
[31] J.-M. Park, R.J.-Y. Kim, K.-W. Lee, Comparative reproducibility analysis of 6 intraoral scanners used on complex intracoronal preparations, J. Prosthet. Dent. 123 (2020) 113–120, https://doi.org/10.1016/j.prosdent.2018.10.025.
[32] A. Tasaka, Y. Uekubo, T. Mitsui, T. Kasahara, T. Takanashi, S. Homma, S. Matsunaga, S. Abe, M. Yoshinari, Y. Yajima, K. Sakurai, S. Yamashita, Applying intraoral scanner to residual ridge in edentulous regions: in vitro evaluation of inter-operator validity to confirm trueness, BMC Oral Health 19 (2019) 264, https://doi.org/10.1186/s12903-019-0918-y.
[33] G. Michelinakis, D. Apostolakis, A. Tsagarakis, G. Kourakis, E. Pavlakis, A comparison of accuracy of 3 intraoral scanners: A single-blinded in vitro study, J. Prosthet. Dent. 124 (2020) 581–588, https://doi.org/10.1016/j.prosdent.2019.10.023.
[34] G. Revell, B. Simon, A. Mennito, Z.P. Evans, W. Renne, M. Ludlow, J. Vág, Evaluation of complete-arch implant scanning with 5 different intraoral scanners in terms of trueness and operator experience, J. Prosthet. Dent. (2021), https://doi.org/10.1016/j.prosdent.2021.01.013.
[35] J. Vág, W. Renne, G. Revell, M. Ludlow, A. Mennito, S.T. Teich, Z. Gutmacher, The effect of software updates on the trueness and precision of intraoral scanners, Quintessence Int 52 (2021) 636–644, https://doi.org/10.3290/j.qi.b1098315.
[36] A.B. Nulty, A Comparison of Full Arch Trueness and Precision of Nine Intra-Oral Digital Scanners and Four Lab Digital Scanners, Dent. J. 9 (2021), https://doi.org/10.3390/dj9070075.