Received: 11 March 2023 | Revised: 3 May 2023 | Accepted: 24 May 2023

DOI: 10.1111/ocr.12682

RESEARCH ARTICLE

Orthodontics & Craniofacial Research WILEY

Evaluation of effects of brackets and orthodontic wires on intraoral scans: A prospective in-vivo study

Mario Palone[1] | Marco Bellavia[1] | Matteo Floris[2] | Andrea Rombolà[1] | Francesca Cremonini[1] | Paolo Albertini[1] | Luca Lombardo[1]

[1]Postgraduate School of Orthodontics, University of Ferrara, Ferrara, Italy

[2]Department of Biomedical Sciences, University of Sassari, Sassari, Italy

Correspondence
Andrea Rombolà, Postgraduate School of Orthodontics, University of Ferrara, Via Luigi Borsari 46, Ferrara 44121, Italy.
Email: andrearombo94@gmail.com

Abstract

Objective: To evaluate any distortion produced by multibracket fixed orthodontic appliances on digital models obtained from intraoral scans (IOS), considering the presence of both brackets only and brackets/archwire combination.

Setting/Sample: The IOS data of the arches of 20 patients (12 females and 8 males; mean age = 15.55 ± 2.84 years) were acquired using the CS3600 intraoral scanner (Carestream Dental, Atlanta, USA), without any appliances (model A), with vestibular brackets alone (model B) and then with brackets and orthodontic archwire fitted (model C).

Materials and Methods: Data were acquired between the months of January and October 2021 at the moment of indirect bonding phase. On each model, five intra-arch linear measurements were obtained (inter-canine, inter-premolar 1 and 2, inter-molar and arch depth), and after digital matching between model A and B (match 1) and A and C (match 2), the linear discrepancies were evaluated at 20 points (10 occlusal and 10 gingivolingual) previous identified on the reference model A. All measurements were performed using Geomagic Control X software (3D Systems, Morrisville, USA), and any dimensional variations and distortions were evaluated by the linear regression analysis and two-sample *t*-test ($P \leq .05$).

Results: The results show an almost perfect correlation between both models B and C and the reference model A, both as regards the intra-arch linear measurements and the linear discrepancies found at the 20 identified points.

Conclusions: Multibracket fixed orthodontic appliances do not produce any relevant distortions in digital models obtained via intraoral scanning. Therefore, the removal of archwire is not mandatory before IOS.

KEYWORDS
accuracy, image distortion, intraoral scanner, intraoral scanning, orthodontic archwire, orthodontic brackets

Abbreviations:: Ad, Arch depth; CAS, computer-assisted surgery; CBCT, Cone Beam Computed Tomography; FACC, Facial axis clinical crown; GL, Gingivolingual; IOS, intraoral scans; Ic, inter-canine width; Ip1, first inter-premolar width; Ip2, second inter-premolar width; Im, inter-molar width; O, Occlusal; SD, standard deviation; VPS, Virtual Surgical Planning; 3D, Three-Dimensional.

1 | INTRODUCTION

In orthodontics, the introduction of intraoral scanners has partly replaced conventional impression materials such as alginates and silicones, with numerous added advantages.[1] Indeed, intraoral scanners enable impressions to be taken whose quality can be immediately assessed with no laboratory phase of pouring,[2] at the same time reducing both costs and discomfort for patients, especially those with a strong gag reflex.[3] In addition, there is no need for physical storage[4] and digital models have greater longevity.[5] Moreover, both the digital workflow and remote communication between different operators are facilitated and more immediate.[6]

Analysing about 35 studies on the subject, Rossini et al. highlighted how digital models obtained via this method are largely faithful to the physical models created using classic impression materials, meaning that they can be reliably used for diagnostic and other orthodontic purposes.[7] These findings were confirmed by a recent systematic review and meta-analysis by Kong et al., who emphasized that intraoral scans (IOS) provide excellent trueness and precision, as compared with models cast using conventional impression materials such as alginate and silicones.[8]

In addition to those already mentioned, a further advantage of intraoral scanners is the possibility of acquiring digital models with fixed appliances in situ, with or without the archwire, which would be impossible when using conventional physical impression materials for the latter. The IOS images with brackets bonded to the vestibular surface of the dental elements yield more faithful reproductions of the gingival areas of each tooth, preventing the stretching that may plague conventional impressions.[9,10] In addition, the IOS images of the arches during orthodontic treatment can be useful in the production of robotically-bent archwires during the finishing phases, in both vestibular and lingual fixed orthodontic treatment.[11,12] For example, Tong et al. described a lingual approach that routinely uses IOS in order to reproduce tooth position at any time of the orthodontic treatment, which can be especially useful in the design of fully customized robotically-bent NiTi archwires in the fine-tuning phase.[13]

The process of acquiring intermediate IOS with fixed appliances in situ is now also routine in the field of orthognathic surgery. The aims are to simulate the physical movement of the basal bones before the surgical phase[10] or to plan the latter digitally (virtual surgical planning, VSP), using computer-assisted surgery (CAS) software.[14] In the latter case, the ability to reproduce the arches with appliances in situ is essential to obtaining adequate matching with the volumetric data acquired via cone beam computed tomography (CBCT) and to manufacture precise surgical splints.[15] Moreover, IOS data can be immediately sent by e-mail, thereby avoiding shipping of conventional impressions and minimizing the risks of physical damage and delays.

Park et al. conducted an in-vitro study performing direct scans on two models, one with the presence of lingual brackets and one with vestibular brackets. The authors demonstrated that both iTero (1st Generation, Align Technology, Santa Clara, CA, USA) and Trios (3Shape, Copenhagen, Denmark) scanners produced faithful reproductions of intra-arch measurements, although the presence of lingual brackets reduced the accuracy of the acquisitions, causing greater magnification of the same.[16] Kim et al. found that the presence of brackets on the vestibular surface of the teeth also generates a magnification error, which they quantified as an average of about 0.097 mm (maximum error 0.150 mm) in the upper arch and about 0.095 mm (maximum error of 0.159 mm) in the lower.[17] Despite these slight discrepancies, however, they concluded that, while it is true that the presence of brackets may decrease the trueness of IOS, they can still be used for orthodontic purposes.

More recently, Kang et al. performed an in-vivo study comparing the effect of fixed vestibular brackets on IOSs produced by two different types of scanners (Trios and iTero). The authors recorded no differences greater than 0.30 mm in any case for either scanner investigated, concluding that digital models acquired with brackets in situ could be used clinically.[18] The same conclusions were drawn by Vargas et al., who found no significant differences between the plaster models and digital models acquired either directly or indirectly, both using the CEREC Omicam scanner (Dentsply Sirona, York, Pa), in the presence of vestibular brackets. They also reported a percentage coincidence between scans acquired directly and those acquired indirectly of about 98.86% ± 0.95% after performing digital superimpositions.[10]

While several studies have previously investigated the accuracy of IOS of both arches with brackets in situ, highlighting generally good trueness and precision, only one, by Jung et al.,[19] has investigated the effect of the presence of the orthodontic archwire. The authors reported very little influence of orthodontic archwire on the accuracy of measurements of both inter-molar and inter-canine distances. However, that was an in-vitro study, which could neither faithfully nor fully simulate the procedure of intraoral scanning of the arches, with both brackets and orthodontic archwires in situ, which may be affected by the presence of saliva,[20–22] and other clinical factors such as limited space or intraoral humidity.[20]

It should be noted too that the presence of an archwire might cause image distortions due to reflection and scattering of the light emitted by the intraoral scanner; this effect would occur away from vestibular surfaces, at both lingual and occlusal surfaces of the teeth, increasing the risk of scanning errors. Moreover, most scanning software processes and rearranges the data initially acquired, and the archwire could be recognized as a foreign body. Hence, further investigations of the effect of the archwire on IOS are warranted.

This is an important issue since the removal and reinsertion of an orthodontic archwire to perform an intraoral scan takes up chairside time, especially when conventional rather than self-ligating brackets are used.[23,24] In fact, Maizeray et al. reported that the minimum chairside time needed to remove and reinsert a 0.014-inch NiTi archwire at the six anterior teeth was about 151.8 seconds for conventional brackets and 21.6 seconds for self-ligating brackets.[24] If we extrapolate this to the time required for the removal and reinsertion of an orthodontic archwire across the entire upper and lower arches, it is clear to see how intraoral scanning with the archwire in situ could save the orthodontist time.

Given the absence of in-vivo data in the literature on this subject, the aim of this study was therefore to identify and quantify any distortion produced by fixed multibracket orthodontic appliances on IOS of the arches, with and without orthodontic archwire inserted. Based on the existing literature, the null hypothesis was that the presence or absence of orthodontic appliances (with or without archwires) would not induce appreciable distortions.

2 | MATERIALS AND METHODS

2.1 | Sample and Data acquisition

The study sample comprised a total of 20 patients (12 females and 8 males; average age = 15.55 years ± 2.84) requiring vestibular fixed orthodontic appliances recruited prospectively at the clinic of Postgraduate School of Orthodontics of the University of Ferrara between the months of January and October 2021. The study design was approved by the ethics committee of the same institution as protocol n° 13/2021.

On the same day as the indirect bonding procedure, three IOSs of each arch in each patient were taken at three different timepoints: before bonding (model A), after bonding (model B) and after placing the orthodontic alignment archwire (model C). The vestibular fixed appliances featured conventional preadjusted metal brackets with 0.022X0.028-inch slots (Primo Bracket, Sweden&Martina, Due Carrare, Italy), and the alignment archwire was a 0.016-inch NiTi (Archform, Sweden&Martina, Due Carrare, Italy). The intraoral scanner (Carestream Dental CS3600, Atlanta, USA) was calibrated and the tip prewarmed before each IOS.[18] After the application of the cheek retractor (Optiview, Ormco, Glendora, USA), the teeth were dried with a brief jet of an air/water syringe, and scans were performed without the use of mattifying powders. Each IOS was conducted by a single experienced operator (MP), following the scanning procedure recommended by the manufacturer. In detail, each IOS procedure began by scanning all the occlusal surfaces of the maxillary arch, moving from the left side of the mouth to the opposite side. Then, the palatal surfaces of the teeth were scanned, moving the intraoral scanner tip in the opposite direction with respect to the previous stage and tilting the tip 45 degrees gingivally. At this stage, the palatal area was included up to at least the first molars, and the IOS procedure continued by scanning the vestibular surfaces of the teeth. Afterwards, the IOS was fine-tuned to fill in any holes on the surfaces. If the scanning software detected a mismatch, a further phase, crossing the tip of intraoral scanner from the lingual to the vestibular side of the teeth, was performed. The scanning protocol was repeated for the mandibular arch, and bite registration at maximum intercuspidation was performed (two registrations per side). The mean time taken for each scan was 6.35 minutes for model A, 9.13 minutes for model B and 10.12 minutes for model C.

No repeated IOSs were performed to test the accuracy of the CS3600 intraoral scanner on model A beforehand, due to the fact that the literature has already reported on its good trueness and precision.[25–28]

Once the scans were obtained and their integrity assessed, they were exported into .STL files for subsequent processing.

The models exported were open-shelled, and the orientation of model was not therefore modified, with the occlusal plane on the X–Y plane and the palatine raphe corresponding to the Y-axis.

2.2 | Measurement method

Any size variations or distortions present were investigated by means of both intra-arch linear measurements and as linear discrepancies at the level of certain points identified on the reference model A, after digital superimposition of the latter with both models B and C, respectively. Geomagic Control X software (3D Systems, Morrisville, USA) was used for this purpose, and all data were gathered by a single operator (MB) experienced in the use of the software.

2.3 | Intra-arch linear measurements

For each model obtained, the following linear measurements (mm) were performed on both the upper and lower arch:

- Inter-canine distance (Ic): measured at the level of the top of the cusps of the canines
- Inter-premolar distance (Ip1): measured at the level of the lingual cusps of the first premolars
- Inter-premolar distance (Ip2): measured at the level of the lingual cusps of the second premolars
- Inter-molar distance (Im): measured at the level of the mesiolingual cusps of the first molars
- Arch depth (Ad): the distance between the interincisal point on the lingual side and an axis passing through the most distal and gingival points on the second molars (Data S1—Supplementary Material 1).

Reference points used for intra-arch linear measurements were placed manually on each model investigated (A, B and C) at the same time and by the same operator (MB).

2.4 | Superimposition method

Further analysis was conducted to measure the linear discrepancies at the occlusal (O) and gingivolingual (GL) points of all teeth (except the lateral incisors and second molars) on models B and C, respectively, with respect to those identified on the surfaces of model A. For the incisors, the O point was identified in the central area of the incisal margin, corresponding to the incisal extension of the facial axis clinical crown (FACC), while for the remaining teeth, the O point was identified as the top of the lingual cusps, previously marked for measurement of the intra-arch distances. For each tooth investigated, the GL points were identified at the central, most gingival, point on the lingual surface. Thus, a total of 20 points were identified for each arch (Data S1—Supplementary Material 2).

Then, three-dimensional (3D) matching was performed between model A, used as reference IOS, and models B and C, respectively, thereby obtaining 3D match 1 (models A and B) and 3D match 2 (A and C) (Data S1—Supplementary Material 2).

In order to get adequate 3D alignment, the areas corresponding to the palatal tissues of maxillary model A and the lingual soft tissues of the mandibular model A were first selected and then fused. After that, model A was aligned with models B and C, respectively, using the '*best-fit alignment*' command. This procedure made it possible to achieve an alignment that would not hinder the detection of possible distortions on the teeth bearing the O and GL points. The linear discrepancies at these points between the superimposed model pairs were revealed using the '*point comparison*' function. Negative linear values indicated that models B and/or C were oversized with respect to model A, while positives value indicated that they were undersized.

The values thereby obtained from both groups of measurements for all the models analysed and categorized according to the type of measurement, were recorded on an Excel spreadsheet (Microsoft, Redmond, Washington, USA).

After about 4 weeks, both intra- and inter-examiner reliability of the measurements performed were investigated by the same (MB) and by a second operator (AR), respectively, by repeating these measurements on models A, B and C on half of the total sample (10 patients). The method error was calculated according to Dahlberg's formula ($S2 = \sum d2/2n$),[29] which revealed intra-examiner reliability values ranging between 0.087 mm and 0.259 mm and inter-examiner reliability values ranging between 0.041 mm and 0.306 mm. The systematic error was calculated via the dependent Student's *t*-test, with $P < .05$ being considered significant. The mean *P*-value, considering both linear intra-arch measurements and linear discrepancies at points after superimposition, was .593 for intra-examiner reliability and .491 for inter-examiner reliability, and no statistically significant differences were found in either case. Analyses thereby confirmed both inter- and intra-examiner reliability of the measurements performed.

2.5 | Statistical Analysis

Intra-arch linear measurements on each arch are reported as means and standard deviation (SD).

Linear discrepancies between the points identified on model A and matched models B and C, respectively, were subjected to descriptive analysis (mean and DS) and are reported taking into account their position. Specifically, the following five point groups were identified:

1. Total: all points
2. Anterior: the points identified on the canines and incisors
3. Posterior: the points identified on the premolars and first molars
4. Occlusal: all O points
5. Lingual: all GL points.

Considering model A as the reference model, the correlation ratios between models A and B and models A and C were calculated for all the intra-arch linear parameters investigated using linear regression. This method enables evaluation of the correlation between the dependent variable (measurements on model B and C) with respect to the independent variable (measurement on model A) for each measurement investigated, assuming a value $R^2 = 1$ in the case of perfect correlation. The correlation ratios described by a *P*-value >.05 were considered statistically different.

Statistical analyses were carried out using the R software (R Foundation for Statistical Computing, Vienna, Austria). The linear discrepancies of the points identified on model A after matching with models B and C were investigated through the paired-sample *t*-test. Statistically significant differences ($P \leq .05$), that is, those that deviated significantly from 0 (the expected value) were considered.

To calculate the β error, a power analysis was performed (1-β error, 0.80; 0.05, one-tailed test). The post-hoc power analysis, conducted using G*power software (version 3.1.9.7; Heinrich-Heine-University, Düsseldorf, Germany), revealed that both sets of measurements had a power of >99%.

3 | RESULTS

3.1 | Intra-arch linear measurements

A descriptive analysis of the linear measurements made on all investigated models and the differences between model A and model B (Δ1), model A and model C (Δ2), and, indirectly, models B and C (Δ1–Δ2) are reported Table 1 as mean and SD. For Δ1, linear discrepancies ranged from a minimum of 0.02 mm ± 0.49 mm (maxillary Ad) and − 0.02 mm ± 0.39 mm (mandibular Ip2) to a maximum of 0.14 mm ± 0.31 mm (mandibular Im), while for Δ2 they ranged from a minimum of 0.01 mm ± 0.44 mm (mandibular Ad) to a maximum of −0.21 mm ± 0.88 (mandibular Ic) and − 0.21 mm ± 0.40 mm (mandibular Im).

While no trend was identified for the maxillary arch, for the mandibular arch there was a decrease in intra-arch distances for both model B (Δ1) and model C (Δ2), with the exception of the measure AP. Considering the total of measurements, there was a minimal difference at the upper arch (0.02 mm ± 0.40 mm for Δ1 and − 0.01 mm ± 0.43 mm for Δ2) but a greater one at the lower arch (Δ1 = -0.04 mm ± 0.49 mm for and Δ2 = -0.09 mm ± 0.52 mm). Evaluation of Δ1 and Δ2 revealed that none of the measurements made deviated by more than 0.10 mm, with model B always being oversized with respect to model C, except for mandibular Ip1 (−0.01 mm ± 0.19 mm) (Table 1).

TABLE 1 Mean and standard deviation of intra-arch linear measurements for both arches. Descriptive differences for matches 1 (Δ1) and 2 (Δ2), and for both matchings (Δ1–Δ2) are reported.

		Model A		Model B		Model C		Model A–Model B (Δ1)		Model A–Model C (Δ2)		Δ1–Δ2	
		Mean (mm)	SD (mm)	Mean (mm)	SD (mm)	Mean (mm)	SD (mm)	Mean (mm)	SD (mm)	Mean (mm)	SD (mm)	Mean (mm)	SD (mm)
Maxilla	Total	38.29	5.52	38.27	5.57	38.31	5.57	0.02	0.40	−0.01	0.43	0.03	0.26
	IC	35.14	2.26	35.10	2.28	35.18	2.36	0.04	0.21	−0.04	0.31	0.08	0.27
	IP1	32.40	2.80	32.29	2.83	32.29	2.85	0.12	0.28	0.12	0.33	0.00	0.24
	IP2	37.24	3.50	37.20	3.54	37.22	3.51	0.04	0.33	0.02	0.29	0.02	0.23
	IM	42.37	3.37	42.49	3.32	42.56	3.32	−0.12	0.56	−0.17	0.58	0.05	0.29
	AD	43.87	4.84	43.85	4.85	43.85	4.85	0.02	0.49	0.02	0.52	0.00	0.26
Mandible	Total	32.15	5.81	32.19	5.73	32.24	5.76	−0.04	0.49	−0.09	0.52	0.05	0.27
	IC	25.74	2.16	25.88	1.85	25.97	1.83	−0.13	0.89	−0.21	0.88	0.08	0.30
	IP1	28.13	2.57	28.16	2.55	28.15	2.54	−0.02	0.29	−0.01	0.31	−0.01	0.19
	IP2	31.53	2.62	31.55	2.60	31.57	2.62	−0.02	0.39	−0.04	0.34	0.02	0.20
	IM	34.83	3.13	34.98	3.19	35.04	3.18	−0.14	0.31	−0.21	0.40	0.07	0.29
	AD	39.90	4.25	39.79	4.19	39.89	4.28	0.11	0.27	0.01	0.44	0.10	0.33

Abbreviations: AD, arch depth; IC, inter-canine width; IM, inter-molar width; IP1, first inter-premolar width; IP2, second inter-premolar width; SD, standard deviation.

The statistical analysis revealed a remarkable correlation between model A and both models B and C for all linear measurements investigated ($P>.05$, $R\simeq 1$) (Table 2). The absolute best correlation between models A and B was Ip2 ($R^2=.992$; $P=4.1e\text{-}20$) in the upper arch (Figure 1A) and Ad ($R^2=.996$; $P=5.47e\text{-}23$) in the lower (Figure 1B). A similar pattern was detected in the comparison between models A and C, with the absolute best correlation in the maxillary arch being recorded for Ip2 ($R^2=0.994$; $P=2.86e\text{-}21$) (Figure 1C), and in the mandibular arch for Ad ($R^2=.989$; $P=4.25e\text{-}19$) (Figure 1D).

Taking into account the total of all the measurements investigated, the best correlation was recorded in the comparison between models A and B in the upper arch ($R^2=.995$; $P=7.06e\text{-}112$) (Figure 2A), while the worst was recorded for the comparison of models A and C in the lower arch ($R^2=.992$; $P=3.46e\text{-}102$) (Figure 2D). In general, however, all measurements showed a very high level of correlation ($R\simeq 1$; $P>0.05$) (Figure 2).

3.2 | Linear discrepancies at points after matching

After performing the respective matchings, both the descriptive analyses (expressed as means and SD) of the linear discrepancies at the level of the points identified on model A, and their statistical comparison by means of the two-sample *t*-test are reported in Table 3. Considering the total of the points investigated and grouped according to their anatomical position (anterior, posterior, lingual and occlusal), in no case was any distortion detected in matches 1 and 2 found to be statistically significant ($P<.05$) (Table 3; Figure 3).

In particular, considering the upper arch alone, the average distortion found in match 1 was 0.017 mm ± 0.14 mm, and in match 2, it was 0.015 mm ± 0.14 mm, indicating that model B and C were slightly undersized with respect to reference model A. In the lower arch, the average distortion found was −0.017 mm ± 0.14 mm in match 1 and − 0.021 mm ± 0.14 mm in match 2, indicating that models B and C were slightly oversized. A further trend detected was that in the upper arch, there was less distortion for match 2, while in the lower arch, the distortion for match 1 was lower. In addition, in the upper arch, the greatest distortions were concentrated in the anterior with respect to the posterior group and in the lingual with respect to the occlusal group. By contrast, in the lower arch, the greatest distortions were concentrated in the posterior, as opposed to the anterior, group but once again in the lingual position with respect to the occlusal.

These findings were the same irrespective of whether an orthodontic archwire was present or absent.

TABLE 2 Statistical comparison using linear regression test regarding intra-arch linear measurements between model A and model B and model A and model C.

		Model A vs. Model B (Δ1)		Model A vs. Model C (Δ2)	
		R^2	*P*-value	R^2	*P*-value
Maxilla	Total	.995	7.06e-112	.994	3.5e−109
	Ic	.991	5.53e−19	.984	1.23e−16
	Ip1	.990	1.62e−18	.987	2.02e−17
	Ip2	.992	4.1e−20	.994	2.86e−21
	Im	.972	1.8e−15	.971	2.58e−15
	Ad	.990	2.36e−19	.988	6.84e−19
Mandible	Total	.993	1.14e−104	.992	3.46e−102
	Ic	.830	2.38e−08	.836	1.71e−08
	Ip1	.987	1.3e−16	.986	3.18e−16
	Ip2	.978	2.74e−16	.983	2.62e−17
	Im	.991	1.06e−19	.984	1.26e−17
	Ad	.996	5.47e−23	.989	4.25e−19

Note: Statistical significance was set at 0.05 ($P>.05^*$).

4 | DISCUSSION

The clinician often needs to perform intermediate IOS on patients with multibracket orthodontic appliance in situ, especially for VSP of orthognathic surgery,[15] and for the design of robotically-bent archwires during the fine-tuning phase of both vestibular and lingual orthodontics,[11–13] and therefore the effect of their presence on IOS warrants investigation. Although the effect of the bracket/archwire combination on IOS has been investigated in-vitro by Jung et al., who reported minimal distortions, informations about the in-vivo effect are still lacking in the literature, and the aim of this study was therefore to provide research on this topic.[19]

Intraoral scanners usually work through a light-emitting process, in most cases without the need for preconditioning of the scanned surfaces, for example with mattifying powders.[22] The light beam emitted by the scanner interacts with the surfaces, and the reflected and refracted light are analysed by the 3D measurement system, with the aid of various technologies. The rebound light is converted into images according to its angle of incidence. The quality of images acquired varies according to the type of materials of the object scanned rather than its morphology. For example, orthodontic accessories like brackets and archwire are usually metallic, and these could create significant image distortion, while other materials, like resin and ceramic, create different degrees of measurement error.[22,30]

Furthermore, in-vivo scan procedures are influenced by various intraoral conditions,[21] in particular saliva.[22] Indeed, saliva acts as a water film of varying thickness, that can modify the pathways of the returning light, leading to measurement error and image distortion. This effect seems to be minimal when confocal microscopy or time-of-flight technologies are used but greater for intraoral scanners that rely on the triangulation method.[31] Kurz et al. reported a measurement error ranging from 300 μm to 1600 μm according to the thickness of water film present,[22] while Camcı et al. reported a 13% deviation in the accuracy of IOS in the presence of saliva.[32]

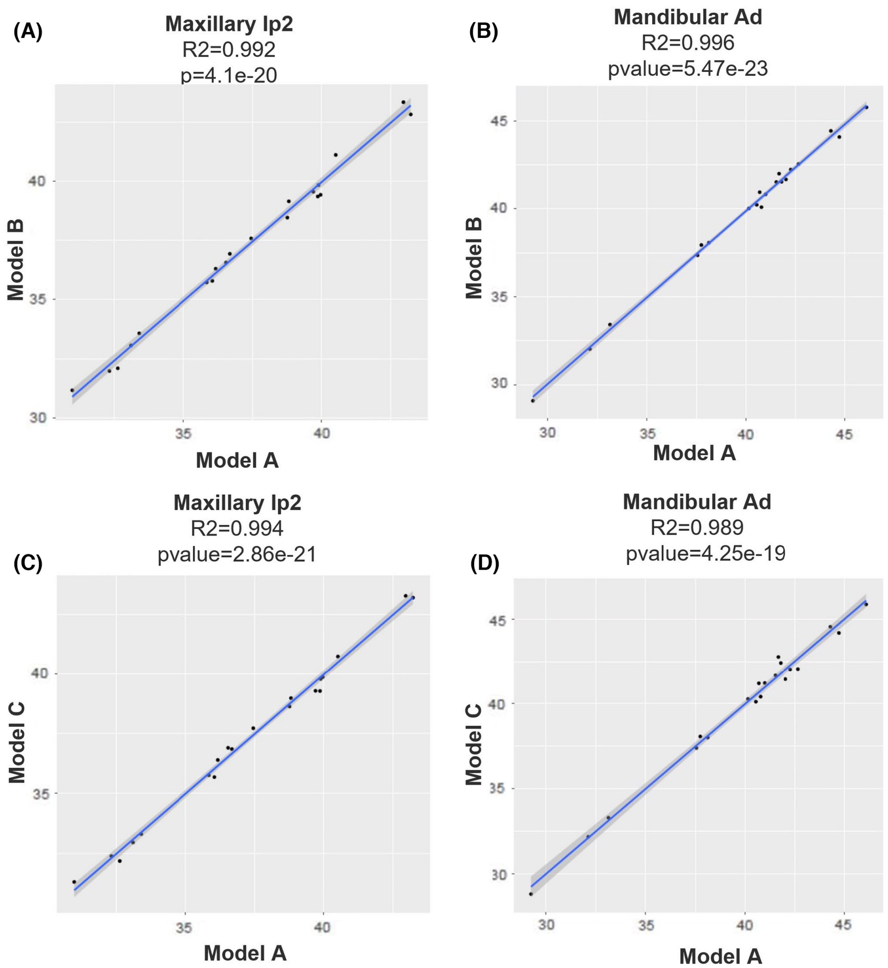

FIGURE 1 Graphical representation of linear regression tests comparing both upper (A) and lower arches (B) of models A and B, and both upper (C) and lower arches (D) of models A and C.

For this reason, in this study the dental surfaces were dried before implementing the IOS procedure.

Although some deficiencies in the acquisition of the inter-dental area can be assumed, especially in those IOSs in which archwires are present, the results of this study are broadly in line with those reported in the literature, when comparing measurements on models taken from IOS data acquired with and without brackets in situ (match 1). Specifically, in this study the average discrepancy between them was 0.04 mm ± 0.21 mm and − 0.13 mm ± 0.89 mm for maxillary and mandibular inter-canine width, and − 0.12 mm ± 0.56 mm and − 0.14 mm ± 0.31 mm for maxillary and mandibular inter-molar width, respectively. These figures are similar to the inter-canine discrepancy of 0.04 mm ± 0.025 mm and 0.07 mm ± 0.27 mm and inter-molar discrepancy of 0.22 mm ± 0.11 mm and 0.25 mm ± 0.18 mm found by Kang et al. for the Trios and iTero scanners,[18] respectively, and the inter-canine discrepancy of 0.14 mm for Trios and 0.20 mm for Itero, and inter-molar discrepancy of 0.36 mm for Trios and 0.16 mm for iTero found by Jung et al.[19]

Like the above studies, the discrepancies found in this investigation were not statistically significant ($R \simeq 1$, $P > .05$), and they followed the same common trend of greater inaccuracy in the posterior sectors (inter-molar distance) with respect to the anterior (inter-canine distance).[17,18] According to Kang et al., reduction in scanning accuracy may depend on the acquisition area in the posterior sectors being more limited.[18] However, the same trend was also noted in the in-vitro study conducted by Jung et al.,[19] so it may be more likely due to the presence of brackets generating greater distortion in the peripheral scanning areas, especially if acquisition relies on stitching-type technology.[16,18,19]

Above all, a comparison of the models generated from IOS taken with and without brackets revealed no significant distortions, with average discrepancy values ranging from 0.017 mm ± 0.14 mm in the upper arch to −0.017 mm ± 0.14 mm in the lower. These discrepancy values are lower than those found by Kim et al., who found that at all points the models with the brackets in situ were slightly oversized (0.097 mm ± 0.028 mm in the upper arch and 0.095 mm ± 0.029 mm in the lower arch).[17] In the direct comparison conducted as part of this study, however, only the lower arch appeared to be oversized. This difference could be due to the fact that in the upper arch, the most peripheral points (posterior area) of the IOS are connected by the palate, which may exert a 'stabilizing' effect, while scanning accuracy of the lower arch, being more u-shaped due to the presence of the tongue, could be more prone to magnification artefacts in the posterior parts. Indeed, in this study, the model with the brackets in situ was also found to be oversized in terms of all mandibular linear measurements except for arch depth (Ad = 0.11 mm ± 0.27 mm). The measurements reported above highlight that the distortion in the lower arch could be likened to the opening of drawing compass:

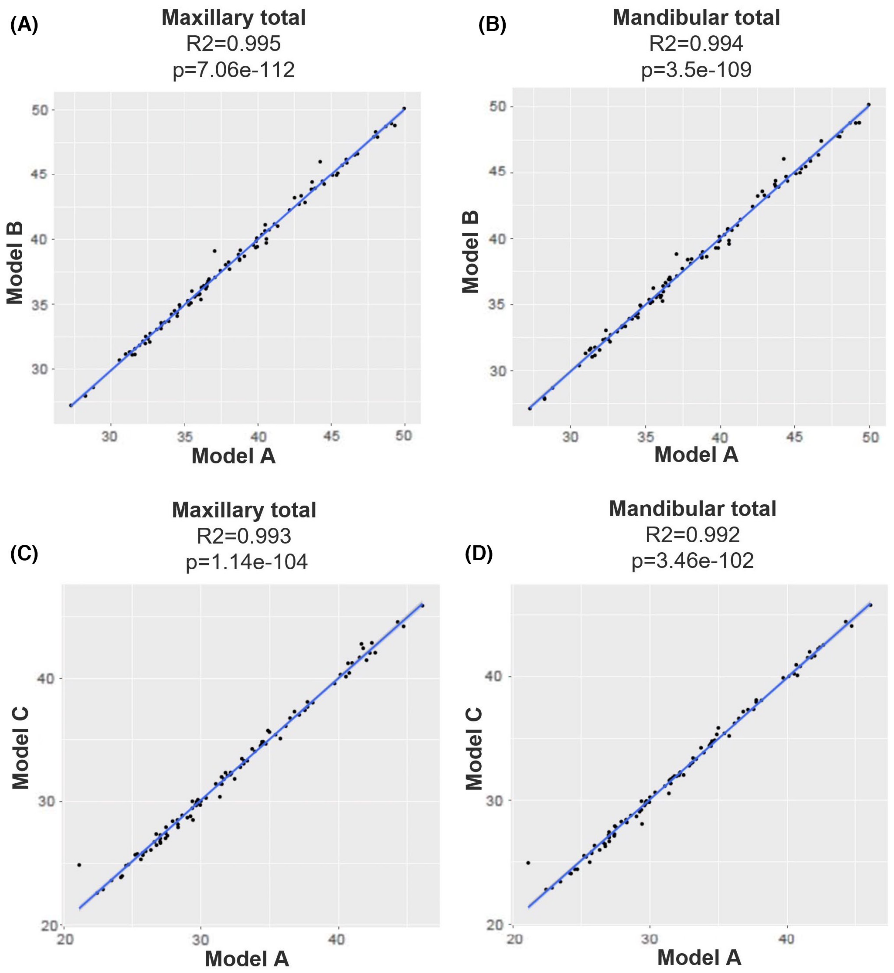

FIGURE 2 Graphical representation of linear regression tests comparing model A and B at both upper (A) and lower arches (B), and model A and C at both upper (C) and lower arches (D), considering all points (total).

TABLE 3 Two-sample *t*-test comparison of linear discrepancies at points identified on model A, after its matching with model B (matching 1) and model C (matching 2).

		Matching 1		Matching 2		
		Mean (mm)	SD (mm)	Mean (mm)	SD (mm)	*P*-value
Maxilla	Total	0.017	0.14	0.015	0.14	.958
	Anterior	0.047	0.13	0.034	0.14	.523
	Posterior	−0.003	0.15	0.002	0.18	.776
	Occlusal	−0.004	0.16	−0.002	0.18	.915
	Lingual	0.038	0.13	0.032	0.14	.710
Mandible	Totota l	−0.017	0.14	−0.021	0.14	.885
	Anterior	−0.007	0.13	−0.015	0.14	.714
	Posterior	−0.030	0.15	−0.033	0.13	.873
	Occlusal	−0.036	0.16	−0.048	0.15	.654
	Lingual	0.002	0.13	0.006	0.12	.695

Note: Statistical significance was set at 0.05 ($P<.05^*$).

its hinge was located in the anterior part of the arch, whereas its tips were in the posterior part, which resulted in more transversally opened.

The different morphology of the scanned arches could also explain the lesser deformation in the posterior areas with respect to the anterior in the upper jaw, with an inverse tendency in the lower jaw, as well as the differences in accuracy found between the occlusal (greater accuracy recorded in the maxilla) and gingivolingual points (greater accuracy in the mandible).

However, beyond these considerations, all data recorded suggest that the presence of vestibular brackets does not affect consistently the reliability of IOS. Hence, as reported in other studies in the literature,[10,17,18] scanning with the brackets in situ can be recommended for routine clinical practice. While there is some

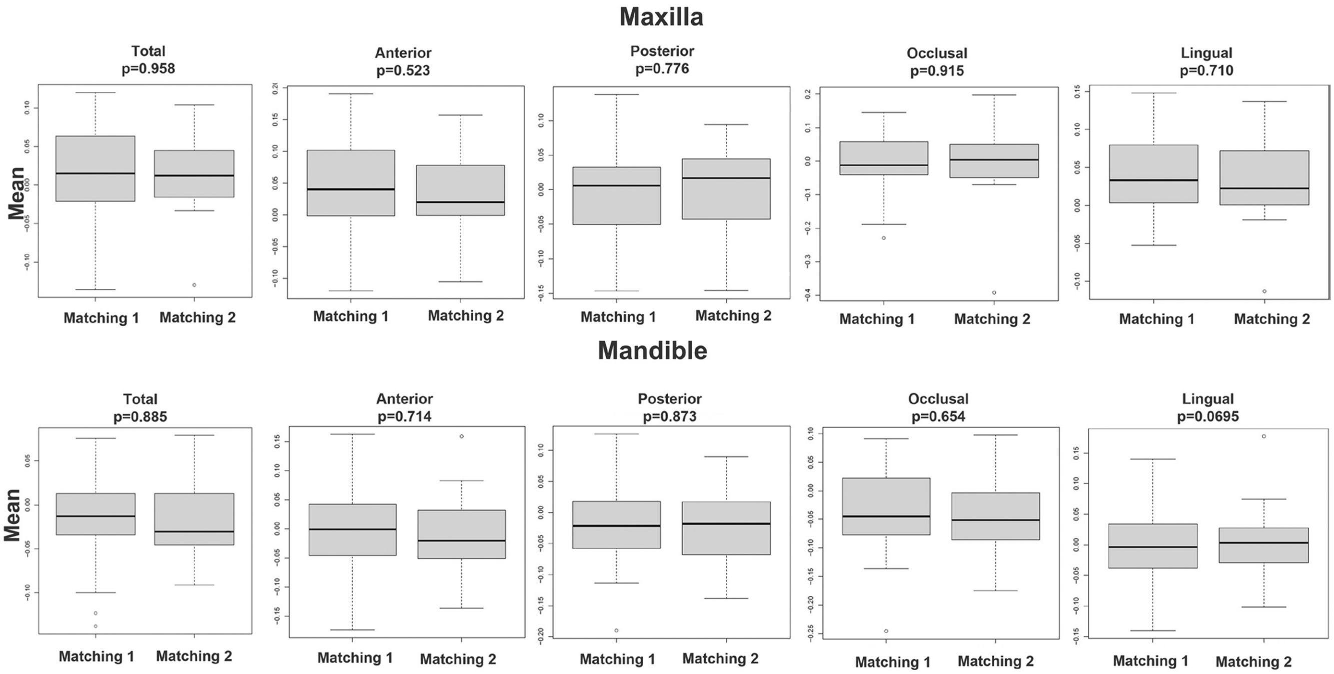

FIGURE 3 Box plots of linear discrepancies at total, anterior, posterior, occlusal and lingual group points identified on model A after matching between model A and B (match 1) and model A and C (match 2).

discrepancy in the literature in terms of the accuracy threshold to adopt, with Hirogaki et al. stating that a digital model can be used for orthodontic purposes when it has an accuracy of approximately 0.3 mm[33] and Schirmer et al.[34] reporting a more stringent 0.2 mm, these threshold values are far in excess of the inaccuracies found in this investigation.

Likewise, the data in this study showed minimal, not statistically significant ($R \simeq 1$, $P > .05$) intra-arch linear discrepancies in both the upper (−0.01 mm ± 0.43 mm) and the lower arch (−0.09 mm ± 0.52 mm) when the scans were taken with the brackets and orthodontic archwire in situ (match 2). Considering the total of the points taken into consideration, although matching revealed minimal linear distortions that never reached statistical significance ($P < .05$), the amount of distortion was lesser in the upper (0.015 mm ± 0.14 mm) with respect to the lower arch (−0.021 mm ± 0.14 mm). This reveals a different trend to that seen when matching the models with and without brackets (match 1), in which the amount of IOS distortion with brackets and archwire in situ is the same, being slightly undersized in the maxillary arch (0.017 mm ± 0.14 mm) and oversized in the mandibular arch (−0.017 mm ± 0.14 mm). Nonetheless, when examining the points grouped according to their anatomical positions, the accuracy trend seen without the archwire inserted (match 1) was repeated with the archwire in situ (match 2), with greater accuracy in the posterior and occlusal areas than in the anterior and gingivolingual in the upper arch, and the reverse pattern in the lower arch.

Considering the intra-arch linear measurements, interestingly the model with the brackets/archwire combination in situ did tend to be slightly oversized with respect to the reference model, which was generally smaller than the model with the brackets alone, with the exception of the mandibular IP1 (−0.01 mm ± 0.19 mm). This indicates that the orthodontic archwire exerts a certain 'contracting' type effect. From this analysis, therefore, it appears that any distortion caused by the archwire did not exacerbate that already caused by the brackets. In other words, IOS can reliably be taken with the archwire in situ. This is good news for clinicians and patients, who can both be spared the time-consuming procedure of removing the archwire before IOS and then reinserting it, which is especially prolonged with conventional brackets.[23,24]

The study, although innovative and designed to fill a gap in the existing literature, has some limitations, which nevertheless lay the foundations for future studies. First of all, only one intraoral scanner, using four-LED active-speed 3D video technology,[35] was investigated, so the same study design should be expanded to other intraoral scanners, and the results categorized according to the acquisition technology used. In addition, the authors acquired the data immediately after clinical bonding (models B and C), although scanning with appliances in situ is generally required at a more advanced stage of therapy, when crowding is usually reduced and the archwires used are made of stainless steel, of greater size and rectangular in shape. It remains to be investigated whether rectangular stainless steel orthodontic archwires of greater thickness generate more pronounced distortion phenomena during image acquisition than the rounded alignment NiTi archwires applied in this study, considering also the fact that stainless steel is one of the most reflective and refractive orthodontic materials. Therefore, further studies will need to investigate the effects of appliances with or without different types of archwires on IOS produced by different intraoral scanners relying on different technologies. Moreover, future studies should also be conducted considering the different materials brackets are made of, such as ceramics, plastics and resin (3D-printed brackets).

5 | CONCLUSIONS

During the acquisition of IOS with Carestream dental CS3600, the presence of brackets with or without archwire produce minimal distortion effects that do not seem to affect their clinical use in the orthodontic field, and the null hypothesis is therefore confirmed. The presence of the orthodontic archwire does not seem to create additional dimensional discrepancies or distortion phenomena, although there is a tendency towards a slight contracting effect. Clinicians may therefore take IOS without the need to disengage the orthodontic archwire.

AUTHOR CONTRIBUTIONS

Marco Bellavia and Luca Lombardo involved in the conception of the study. Mario Palone, Francesca Cremonini and Paolo Albertini involved in data collection. Matteo De Floris involved in statistical analysis. Mario Palone and Andrea Rombolà involved in drafting the manuscript. Luca Lombardo and Mario Palone involved in the critical revision of the manuscript for important intellectual content. Mario Palone, Paolo Albertini, Francesca Cremonini, Matteo De Floris, Marco Bellavia, Andrea Rombolà and Luca Lombardo involved in the approval of the final version of the manuscript to be published.

ACKNOWLEDGEMENTS

Not applicable.

FUNDING INFORMATION

There are no sponsors for this study. The research is funded by its own means of the experimenters.

CONFLICT OF INTEREST STATEMENT

The authors declare they have no commercial or financial gain pertaining to any included appliance in this study.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICS APPROVAL

Ethical approval of the institutional review board of the Postgraduate School of Orthodontics of the University of Ferrara and the informed consent release were obtained.

CONSENT FOR PUBLICATION

Not applicable.

ORCID

Mario Palone https://orcid.org/0000-0001-6198-3053
Paolo Albertini https://orcid.org/0000-0002-4020-5065

REFERENCES

1. Kravitz ND, Groth C, Jones PE, Graham JW, Redmond WR. Intraoral digital scanners. *J Clin Orthod*. 2014;48(6):337-347.
2. Zimmermann M, Mehl A, Mörmann WH, Reich S. Intraoral scanning systems—a current overview. *Int J Comput Dent*. 2015;18(2):101-129.
3. Grünheid T, McCarthy SD, Larson BE. Clinical use of a direct chairside oral scanner: an assessment of accuracy, time, and patient acceptance. *Am J Orthod Dentofacial Orthop*. 2014;146(5):673-682.
4. Marcel T. Three-dimensional on-screen virtual models. *Am J Orthod Dentofacial Orthop*. 2001;119:666-668.
5. Hazeveld A, Huddleston Slater JJ, Ren Y. Accuracy and reproducibility of dental replica models reconstructed by different rapid prototyping techniques. *Am J Orthod Dentofacial Orthop*. 2014;145(1):108-115.
6. Sousa MV, Vasconcelos EC, Janson G, Garib D, Pinzan A. Accuracy and reproducibility of 3-dimensional digital model measurements. *Am J Orthod Dentofacial Orthop*. 2012;142:269-273.
7. Rossini G, Parrini S, Castroflorio T, Deregibus A, Debernardi CL. Diagnostic accuracy and measurement sensitivity of digital models for orthodontic purposes: a systematic review. *Am J Orthod Dentofacial Orthop*. 2016;149(2):161-170.
8. Kong L, Li Y, Liu Z. Digital versus conventional full-arch impressions in linear and 3D accuracy: a systematic review and meta-analysis of in vivo studies. *Clin Oral Investig*. 2022;26:5625-5642.
9. Sunil G, Ram R, Ranganayakulu I. Taking impressions in patients with brackets in place. *J Clin Orthod*. 2019;53(9):535-536.
10. Amaral Vargas EO, Otero Amaral Vargas D, da Silva CR, Franzotti Sant'anna E, Melo PM. Impact of orthodontic brackets on intraoral and extraoral scans. *Am J Orthod Dentofacial Orthop*. 2022;S0889-5406(22):00132-00139.
11. Alford TJ, Roberts WE, Hartsfield JK Jr, Eckert GJ, Snyder RJ. Clinical outcomes for patients finished with the SureSmile™ method compared with conventional fixed orthodontic therapy. *Angle Orthod*. 2011;81(3):383-388.
12. Müller-Hartwich R, Jost-Brinkmann PG, Schubert K. Precision of implementing virtual setups for orthodontic treatment using CAD/CAM-fabricated custom archwires. *J Orofac Orthop*. 2016;77(1):1-8.
13. Elnagar MH, Aronovich S, Kusnoto B. Digital workflow for combined orthodontics and Orthognathic surgery. *Oral Maxillofac Surg Clin North Am*. 2020;32(1):1-14.
14. Tong H, Weissheimer A, Pham J, Lee R, Redmond WR. Lingual orthodontics redefined with automation and friction-free mechanics. *J Clin Orthod*. 2019;53(4):214-224.
15. Ye N, Wu T, Dong T, Yuan L, Fang B, Xia L. Precision of 3D-printed splints with different dental model offsets. *Am J Orthod Dentofacial Orthop*. 2019;155(5):733-738.
16. Park JM, Choi SA, Myung JY, Chun YS, Kim M. Impact of orthodontic brackets on the intraoral scan data accuracy. *Biomed Res Int*. 2016;2016:5075182.
17. Kim YK, Kim SH, Choi TH, et al. Accuracy of intraoral scan images in full arch with orthodontic brackets: a retrospective in vivo study. *Clin Oral Investig*. 2021;25(8):4861-4869.
18. Kang SJ, Kee YJ, Lee KC. Effect of the presence of orthodontic brackets on intraoral scans. *Angle Orthod*. 2021;91(1):98-104.
19. Jung YR, Park JM, Chun YS, Lee KN, Kim M. Accuracy of four different digital intraoral scanners: effects of the presence of orthodontic brackets and wire. *Int J Comput Dent*. 2016;19(3):203-215.
20. Flügge TV, Schlager S, Nelson K, Nahles S, Metzger MC. Precision of intraoral digital dental impressions with iTero and extraoral digitization with the iTero and a model scanner. *Am J Orthod Dentofacial Orthop*. 2013;144(3):471-478.
21. Sun L, Lee JS, Choo HH, Hwang HS, Lee KM. Reproducibility of an intraoral scanner: a comparison between in-vivo and ex-vivo scans. *Am J Orthod Dentofacial Orthop*. 2018;154(2):305-310.
22. Kurz M, Attin T, Mehl A. Influence of material surface on the scanning error of a powder-free 3D measuring system. *Clin Oral Investig*. 2015;19(8):2035-2043.

23. Chen SS, Greenlee GM, Kim JE, Smith CL, Huang GJ. Systematic review of self-ligating brackets. *Am J Orthod Dentofacial Orthop*. 2010;137(6):726.e1-726.e18. discussion 726–7.
24. Maizeray R, Wagner D, Lefebvre F, Lévy-Bénichou H, Bolender Y. Is there any difference between conventional, passive and active self-ligating brackets? A systematic review and network meta-analysis. *Int Orthod*. 2021;19(4):523-538.
25. Imburgia M, Logozzo S, Hauschild U, Veronesi G, Mangano C, Mangano FG. Accuracy of four intraoral scanners in oral implantology: a comparative in vitro study. *BMC Oral Health*. 2017;17(1):92.
26. Mangano FG, Admakin O, Bonacina M, Lerner H, Rutkunas V, Mangano C. Trueness of 12 intraoral scanners in the full-arch implant impression: a comparative in vitro study. *BMC Oral Health*. 2020;20(1):263.
27. Kim MK, Son K, Yu BY, Lee KB. Effect of the volumetric dimensions of a complete arch on the accuracy of scanners. *J Adv Prosthodont*. 2020;12(6):361-368.
28. Pellitteri F, Albertini P, Vogrig A, Spedicato GA, Siciliani G, Lombardo L. Comparative analysis of intraoral scanners accuracy using 3D software: an in vivo study. *Prog Orthod*. 2022;23(1):21.
29. Dahlberg G. *Statistical Methods for Medical and Biological Students*. George Allen and Unwin, Ltd.; 1940.
30. Song J, Kim M. Accuracy on scanned images of full arch models with orthodontic brackets by various intraoral scanners in the presence of artificial saliva. *Biomed Res Int*. 2020 Feb;27(2020):2920804-2920808.
31. Logozzo S, Zanetti EM, Franceschini G, Kilpelä A, Mäkynen A. Recent advances in dental optics—part I. 3D intraoral scanners for restorative dentistry. *Opt Lasers Eng*. 2014;54:203-221.
32. Camcı H, Salmanpour F. Effect of saliva isolation and intraoral light levels on performance of intraoral scanners. *Am J Orthod Dentofacial Orthop*. 2020;158(5):759-766.
33. Hirogaki Y, Sohmura T, Satoh H, Takahashi J, Takada K. Complete 3-D reconstruction of dental cast shape using perceptual grouping. *IEEE Trans Med Imaging*. 2001;20(10):1093-1101.
34. Schirmer UR, Wiltshire WA. Manual and computer-aided space analysis: a comparative study. *Am J Orthod Dentofacial Orthop*. 1997;112(6):676-680.
35. Nagy Z, Simon B, Mennito A, Evans Z, Renne W, Vág J. Comparing the trueness of seven intraoral scanners and a physical impression on dentate human maxilla by a novel method. *BMC Oral Health*. 2020;20(1):97.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Palone M, Bellavia M, Floris M, et al. Evaluation of effects of brackets and orthodontic wires on intraoral scans: A prospective in-vivo study. *Orthod Craniofac Res*. 2023;00:1-11. doi:10.1111/ocr.12682