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Evaluation of scanning accuracy for two commercially available intraoral scanners in reproducing orthodontic bracket dimensions

A. SELVARAJ[1], S.P. SARAVANA DINESH[1], A. SIVAKUMAR[1], T.R.P. ARVIND[1], D.H. ALBAR[2], A. ALSHEHRI[3], W. AWADH[3], K.J. ALZAHRANI[4], I.F. HALAWANI[4], S. ALSHAMMERI[5], H.A. BAESHEN[6], S. PATIL[7]

[1]Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai, India
[2]Preventive Dentistry, College of Dentistry, Jazan University, Jazan, Saudi Arabia
[3]Department of Preventive Dental Sciences, Faculty of Dentistry, Jazan University, Division of Orthodontics, Jazan, Saudi Arabia
[4]Department of Clinical Laboratories Sciences, College of Applied Medical Sciences, Taif University, Taif, Saudi Arabia
[5]Department of Optometry, College of Applied Medical Sciences, Qassim University, Buraydah, Saudi Arabia
[6]Department of Orthodontics, Faculty of Dentistry, King Abdulaziz University, Jeddah, Saudi Arabia
[7]College of Dental Medicine, Roseman University of Health Science, South Jordan, Utah, USA

Abstract. – OBJECTIVE: The aim of this study was to compare the scanning accuracy of two different intra-oral scanners- MEDIT i500 and TRIOS 3 shape in reproducing orthodontic bracket dimensions.

MATERIALS AND METHODS: This *in vivo* cross-sectional study comprised seven subjects with a full complement of permanent dentition without third molars. Complete arch scanning was carried out with two intraoral scanners, such as MEDIT i500, TRIOS 3 shape, after bonding with brackets. The control group consisted of bracket dimensions measured directly by using Vernier calipers before bonding. Bracket dimensions of three-dimensional (3D) images were measured by using OrthoAnalyzer software. The accuracy of intraoral scanning was investigated by comparing bracket dimensions among the three groups using One-way ANOVA and Post-Hoc Tukey HSD test, and by evaluating outcomes for each quadrant and an individual tooth in complete-arch scans.

RESULTS: When comparing bracket dimensions of 3D images with manual measurements using a traditional Vernier caliper, MEDIT i500 showed no significant difference when compared to the control group (*p*>0.05) in full arch scanning as well as the quadrant and single tooth scans in complete arch scanning. TRIOS 3 shape showed a significant difference when compared to the control and MEDIT i500 group (*p*<0.05) for all parameters.

CONCLUSIONS: MEDIT i500 showed higher accuracy and better reproduction of orthodontic bracket dimensions than TRIOS 3 shape.

Key Words:
Accuracy, Bracket dimensions, MEDIT i500, TRIOS 3 Shape.

Introduction

The success of orthodontic treatment depends on both an accurate initial diagnosis and an accurate assessment of treatment progress. With developments in 3D technology, newer diagnostics aids such as digital models, intra-oral scans, Cone Beam Computed Tomography (CBCT), etc., are now replacing traditional plaster casts, patient photographs, and lateral cephalograms, due to their better diagnostic accuracy, and ease of storage and retrieval of records[1,2]. Although plaster casts are still considered the gold standard, there are certain related disadvantages such as time for fabrication and measurements of casts, weight and volume, demand on storage space, fragility, difficulty in exchanging information with other professionals, and frequent measurements can cause physical damage which may lead to inaccuracy[3,4]. To overcome most of these limitations, in 2001, OrthoCAD™ (Cadent, Carlstadt, NJ, USA) proposed the use of digital models obtained by either direct intraoral scanning or indirect scanning of impressions or plaster models[5]. Over the last decade, the uses of

Corresponding Authors: Saravana Dinesh, MD; e-mail: drsaravanadinesh@gmail.com; Shankargouda Patil, MD; e-mail: spatil@roseman.edu

intraoral scanners have sparked renewed interest, representing a paradigm shift in orthodontics[6]. In approximately 24% of cases, viewing digital setups resulted in changes to treatment plans, as well as increased practitioners' overall confidence, especially for challenging cases[5,7].

Previous studies and systematic reviews[8-15] have shown that digital setups may be an effective, accurate, reliable, and reproducible tool for orthodontic diagnosis and treatment planning compared to conventional manual models. However, they may still be vulnerable to inaccuracies under clinical conditions with variables such as scanner type, span of scanning, operator experience[16-18], etc. Recently, many *in-vitro* and *in-vivo* studies[19-22] comparing accuracy with orthodontic brackets have shown that intraoral scans are less prone to error, provide more detailed measurements, and are clinically acceptable with regions up to 0.50 mm surrounding the brackets that could be used for superimpositions on images without brackets. An overview[23] has stated that intraoral scanners may be an alternative option for traditional impressions in future orthodontics. When compared to traditional impression techniques, digital impression reduces chair time, patient discomfort, contamination from saliva, and the possibility of debonding brackets, especially with lingual braces and orthodontic attachments/wires[21]. As an additional perk, it helps create mid-treatment orthodontic records required to design and construct clear aligner and lingual appliances, tray fabrication for indirect bonding, and, most recently, analyzing surgical outcome scores for cleft lip and cleft palate patients[24-30]. In virtual surgical treatment planning, CT scans must be integrated with digital scans, especially for designing margins of surgical splints based on the position of the brackets[31]. Hence digital scanners are required to reproduce brackets accurately, especially in the fabrication of surgical splints[19,21,32,33].

In order to provide clinically acceptable results, we cannot presume that all intraoral scanners would produce comparable data. MEDIT i500 & TRIOS 3 shape scanners allow full-arch scanning without powdering the teeth. Moreover, these two scanners have orthodontic application software. To our knowledge, these two scanners are the most widely used commercial intraoral scanners in dentistry. Hence it is important to assess its relative scanning accuracy in the reproduction of orthodontic bracket dimensions.

Therefore, the present study aimed to determine the scanning accuracy of two different intra-oral scanners, such as MEDIT i500 & TRIOS 3 shape in reproducing orthodontic bracket dimensions.

Materials and Methods

This *in-vivo* cross-sectional study was conducted in the Department of Orthodontics, of Saveetha Dental College. Ethical clearance for the study protocol was obtained from the Saveetha Institutional Review Board, SIMATS University, to conduct this research (I.E.C. No: IHEC/SDC/ORTHO/-1907/22/381).

Sample Selection

The sample size for the study was estimated using G power software version 3.0.10. (Heinrich Heine University, Dusseldorf, Germany). A study conducted by Tepedino et al[34] was used for the purpose of sample size calculation. The alpha level and power were set at 0.05 and 95%, respectively, for sample size calculation, which was estimated to be 14. Thus, for a total of 14 scans/dental arches needed, a study sample of seven subjects had to be chosen in each of the two groups for intra-oral scanning. Randomly, seven individuals who reported to the department were randomly included in the study based on the following inclusion criteria: pretreatment subjects for fixed orthodontic treatment with direct bonding of brackets, a full complement of permanent dentition except for third molars, patients with less than 3 mm of crowding. Exclusion criteria were lack of cooperation, a grossly decayed tooth, proximal wear, enamel fractures, and prosthesis on the dentition.

Subjects who gave written informed consent for the study were finally included.

The sample was divided into the following three groups:

- Group A: In the control group, bracket dimensions were measured using Vernier caliper before bonding (n=7).
- Group B: All Subjects were scanned with MEDIT i500 intraoral scanner after bonding with brackets (n=7).
- Group C: All Subjects were scanned with TRIOS 3 shape intraoral scanner after bonding with brackets (n=7).

Direct Measurements of Brackets

The 0.022 slot pre-adjusted standard edgewise (Gemini -3M Unitek™, Monrovia, CA, USA) metal brackets with MBT (McLaughlin, Bennett, and Trevisi) prescription were used in all subjects. For

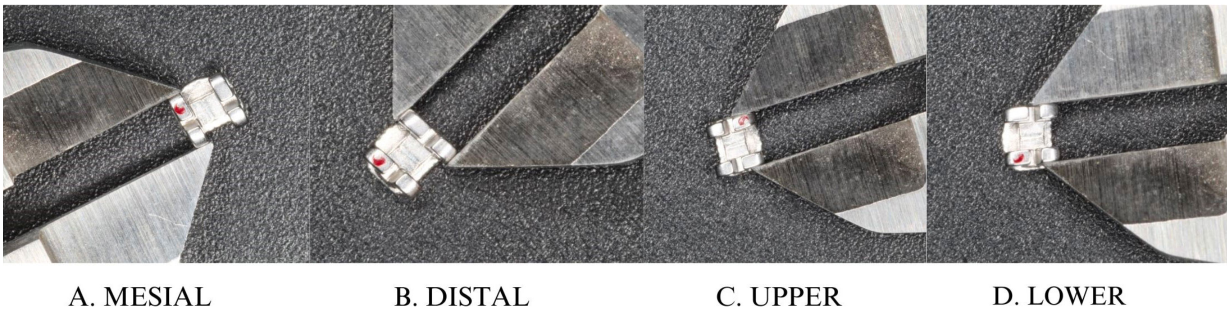

Figure 1. Width of the mesiodistal [(**A**) Mesial, and (**B**) Distal] and occluso-gingival [(**C**) Upeer and (**D**) Lower] wings of the orthodontic brackets were determined with calipers for all brackets.

the control group, direct measurements of bracket dimensions were recorded for each bracket using digital Vernier calipers providing measurements of 0.01 mm accuracy. The width of the mesiodistal (upper and lower) and occluso-gingival (mesial and distal) wings of the orthodontic brackets were determined (Figure 1). Hooks were included in the measurements of canine and premolar brackets to obtain the optimum dimensions of the brackets. All seven subjects were bonded with these brackets and then subjected to intraoral scanning with two intraoral scanners for the remaining groups.

Measurements of Brackets Using Intraoral Scanners

Intraoral scanning was performed on all seven subjects using the same two intraoral scanners such as TRIOS (3Shape, Copenhagen, Denmark) (Figure 2) and MEDIT (i500, Medit Corp., Seoul, South Korea) (Figure 3). There was no order in which the subjects were scanned, and no powder spray was used on the tooth surface while scanning. The manufacturer's recommended scan strategy was used to scan the arches for optimum accuracy. After scanning, all the data from two intraoral scanners were transferred to the OrthoAnalyzer TM (3Shape, Copenhagen, Denmark) software program and converted to stereolithography (STL) files. The width of the mesiodistal (upper and lower) and occluso-gingival (mesial and distal) wings of the orthodontic brackets were measured by using an analyzer tool of OrthoAnalyzer software (Figure 4). Bracket dimensions were measured for three teeth per quadrant: the second premolar, canine, and central incisor. A total of 6 bracket dimensions per arch were measured for each patient by using these two intraoral scanners. Scanning with intraoral scanners was done by a technically skilled clinician.

For each bracket, the dimension was calculated by averaging the widths of the two measurements.

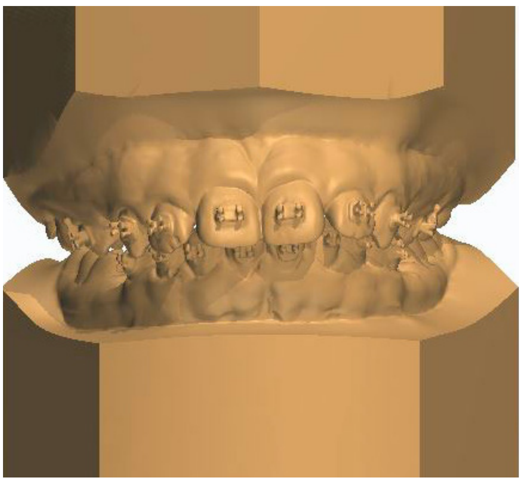

Figure 2. Digital models obtained with TRIOS 3 shape intraoral scanner.

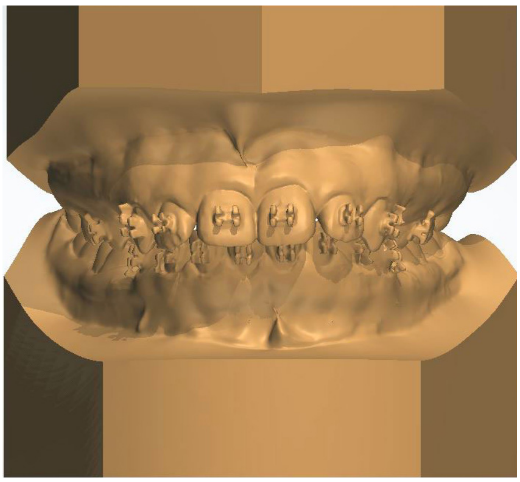

Figure 3. Digital models obtained with MEDIT i500 intraoral scanner

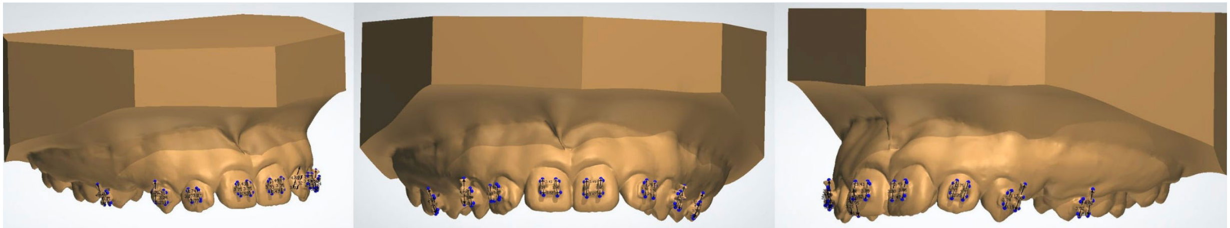

Figure 4. The orthodontic bracket measurements were determined in digital models by using an analyzer tool of ortho analyzer software.

Data were also compared separately as the quadrant and single tooth scans from complete arch scans to determine the factors that influence the accuracy of intraoral complete arch scanning data.

Direct measurements of orthodontic brackets using a Vernier caliper were done by the first author, and measurements of brackets using intraoral scanners were done by the second author. Inter and Intra-examiner reliability of the measurements was determined to reduce the assessment bias by repeating all the measurements after a week for 20% of randomly selected samples. Intraclass correlation coefficients were used to determine reliability, and the reliability tests proved to be excellent for all the measurements.

Statistical Analysis

The collected data were tabulated in an Excel workbook (Microsoft Excel 2016) and later transferred to SPSS Software Version 23, (IBM Corp., Armonk, NY, USA) for statistical analysis. One-way ANOVA and Post-Hoc Tukey HSD test were performed to compare the measurements of bracket dimensions among the three groups in complete-arch scanning and also evaluated for each quadrant as well as an individual tooth in complete-arch scans to determine the factors that influence the accuracy of intraoral scanning. $p<0.05$ was considered statistically significant.

Results

Descriptive statistics and results of One-way ANOVA for complete arch scanning and also for quadrant and individual tooth scans in complete arch scans are shown in Tables I, II, and III, respectively.

For complete arch scanning, MEDIT i500 showed no significant difference compared to the control ($p=0.780$), indicating greater accuracy and better reproduction of orthodontic bracket dimensions.

But TRIOS 3 shape showed a greater significant difference ($p=0.000$) with a mean discrepancy of 0.62 mm and 0.57 mm compared to control and MEDIT i500, respectively, indicating less accuracy in reproducing orthodontic bracket dimensions (Table I).

For quadrant arch scans in complete arch scans, MEDIT i500 showed no significant difference compared to control indicating greater accuracy in the first quadrant ($p=0.918$) followed by the third quadrant ($p=0.867$), second quadrant ($p=0.497$), and fourth quadrant ($p=0.163$). But TRIOS 3 shape showed a greater significant difference ($p=0.000$) with a mean discrepancy of 0.50 mm and 0.49 mm in first quadrant, 0.5 mm and 0.53 mm in second quadrant, 0.76 mm and 0.72 mm in third quadrant, 0.72 mm and 0.61 mm in fourth quadrant compared to control and MEDIT i500, respectively, which

Table I. One Way ANOVA with post-hoc Tukey HSD showed a comparison of bracket dimensions measurements among three groups for complete arch scanning.

S.NO	Variable	N	Control (A) Mean±SD	MEDIT (B) Mean±SD	TRIOS (C) Mean±SD	ANOVA *p*-value	A-B	B-C	C-A
1	Full arch scanning	21	3.42±0.69	3.39±0.70	2.82±0.58	0.000	0.780	0.000	0.000

CAD: coronary artery disease, CHF: congestive heart failure, LDH: lactate dehydrogenase,CRP: C-reactive protein, NLR: neutrophil-lymphocyte ratio, AST: aspartate aminotransferase, ALT: alanin aminotransferase, SOFA: sequential organ failure assessment, SIC:sepsis-induced coagulopathy, LMWH: low-molecular-weight heparin.

Table II. One Way ANOVA with post-hoc Tukey HSD showed a comparison of bracket dimensions measurements among three groups for quadrant arch scans in complete arch scans.

S.NO	Variable	N	Control (A) Mean±SD	MEDIT (B) Mean±SD	TRIOS (C) Mean±SD	ANOVA *p*-value	A-B	B-C	C-A
1	First quadrant	21	3.51±0.00	3.50±0.00	3.01±0.07	0.000	0.918	0.000	0.000
2	Second quadrant	21	3.54±0.00	3.57±0.03	3.04±0.04	0.000	0.497	0.000	0.000
3	Third quadrant	21	3.32±0.00	3.28±0.23	2.56±0.15	0.000	0.867	0.000	0.000
4	Fourth quadrant	21	3.31±0.00	3.20±0.31	2.59±0.09	0.000	0.163	0.000	0.000

Table III. One Way ANOVA with post-hoc Tukey HSD showed a comparison of bracket dimensions measurements among three groups for single tooth scans in complete arch scans.

S.NO	Tooth number	N	Control (A) Mean±SD	MEDIT (B) Mean±SD	TRIOS (C) Mean±SD	ANOVA *p*-value	A-B	B-C	C-A
1	15	21	3.61±0.10	3.59±0.01	3.31±0.03	0.000	0.186	0.000	0.000
2	13	21	3.61±0.12	3.61±0.34	2.72±0.19	0.000	1.000	0.000	0.000
3	11	21	3.32±0.22	3.32±0.20	2.99±0.08	0.000	0.969	0.000	0.000
4	21	21	3.39±0.13	3.39±0.19	2.97±0.05	0.000	0.548	0.000	0.000
5	23	21	3.60±0.11	3.62±0.03	3.07±0.04	0.000	1.000	0.000	0.000
6	25	21	3.63±0.10	3.71±0.11	3.07±0.12	0.000	0.305	0.000	0.000
7	45	21	3.57±0.11	3.46±0.20	2.91±0.18	0.000	0.413	0.000	0.000
8	43	21	3.57±0.15	3.57±0.16	2.83±0.23	0.000	1.000	0.000	0.000
9	41	21	2.83±0.19	2.81±0.34	1.94±0.28	0.000	0.990	0.000	0.000
10	31	21	2.82±0.18	2.81±0.25	2.24±0.16	0.000	0.995	0.000	0.000
11	33	21	3.56±0.20	3.37±0.41	2.80±0.19	0.000	1.000	0.001	0.000
12	35	21	3.56±0.17	3.41±0.30	2.73±0.11	0.000	0.330	0.000	0.000

indicates less accuracy in replicating orthodontic bracket dimensions (Table II).

For individual teeth scans in complete arch scans, MEDIT i500 showed no significant difference compared to the control indicating greater accuracy for all individual teeth and also showed greater accuracy, especially for tooth numbers 13, 23, 33, and 43 (p=1.000), indicating that MEDIT i500 can replicate the bracket dimensions more accurately on anteriors compared to posteriors in both maxilla and mandible. However, TRIOS 3 shape showed a greater significant difference for all teeth, especially for mandibular incisors, when compared to the other two groups (p<0.05), indicating less accuracy in replicating orthodontic bracket dimensions (Table III).

Discussion

In recent years, advances in 3D technology have resulted in the widespread use of digital models in dentistry, especially in orthodontics, for diagnosis and treatment planning. The accuracy of intraoral scanners in reproducing orthodontic bracket dimensions by scanning the patients bonded with brackets has not been addressed. To our knowledge, this is the first study to compare the accuracy of intraoral scanners in reproducing the dimensions of orthodontic brackets and also addresses a void in its routine use in orthodontics.

During the active phase of orthodontic treatment, impressions of patients' dentitions are more frequently taken for assessing the occlusion and also for monitoring and evaluating tooth movement. Hence complete arch scanning is more necessary and useful[35-37]. However, as the scanning area increases, the scanning accuracy decreases due to several factors[38]. Prior to being accepted as the new standard for orthodontic purposes, the intraoral complete arch scan must be accurate in all clinical circumstances. Orthodontic attachments such as brackets, bands, and wires may result in lower accuracy than natural dentition. *In-vitro* studies[19,21] showed that brackets significantly impacted arch dimensions. In this regard, the current study aimed to evaluate the accuracy of two intraoral scanners in reproducing orthodontic bracket dimensions as well as the factors influencing the accuracy of complete arch scanning. When compared to actual dimensions from the control group, MEDIT i500 showed greater accuracy and better reproduction of orthodontic brackets dimensions than TRIOS 3 shape in complete arch scanning. Our present study contradicts the results of previous studies[19-20,39] that have claimed that TRIOS 3 shape showed acceptable clinical accuracy in the presence of orthodontic metal brackets in terms of horizontal measurements and arch width dimensions. More recently, two studies[21,40] have shown that TRIOS 3 shape obtained more precise and accurate dimensions of brackets compared to MEDIT i500. In our study, additionally, we have noticed that bracket wings were not properly captured in TRIOS 3 shape compared to MEDIT i500. This may be due to different processes of stitching the scanned images as well as different methods of image acquisition between the scanners that may affect the accuracy of brackets dimensions. Even so, there have been so many diverse scanner results that no specific intraoral scanner can be considered the best.

Complete arch scanning may be enhanced by taking into consideration a number of factors. Hence assessment of quadrant arch and single tooth scans in complete arch scans would help determine the factors that influence the accuracy of intraoral complete arch scanning. MEDIT i500 showed higher accuracy and better reproduction of orthodontic brackets dimensions than TRIOS 3 shape for quadrant arch scans in complete arch scans. MEDIT i500 reproduces bracket dimensions with greater accuracy in the first quadrant (p=0.918) followed by the third quadrant (p=0.867), second quadrant (p=0.497), and fourth quadrant (p=0.163). Additionally, we have noticed that distortion was greater in brackets wings of premolar compared to the canine in TRIOS 3 shape compared to MEDIT i500. This may be due to the direction of scanning. As the scanner moves from right to left, the variance may accumulate on the right and posterior regions. This was supported by previous studies[20,41,42] which claimed that scanning direction may also be one of the factors which may affect accuracy. Interestingly, for the upper arch, accuracy can be found more in the second quadrant compared to the first quadrant, and for the lower arch, accuracy is more found in the third quadrant compared to the fourth quadrant. This may be due to the right-handed clinician performing all scans, as manual dexterity may influence the accuracy in those specific quadrants. In fact, the right-handed clinician can easily operate on the second quadrant in the upper arch and the third quadrant in the lower arch compared to the left-handed clinician. Another reason could be either the difficult accessibility of the scanners' head in posterior regions, the specific algorithm of the software employed in scanners, or other aspects of the oral environment[19,21,40,43]. Another finding is that accuracy can be found more in the maxilla than in the mandible, and this may be due to the presence of tongue interference during mandibular scanning[19].

For single teeth scans from complete arch scans, MEDIT i500 showed higher accuracy and better reproduction of orthodontic bracket dimensions than TRIOS 3 shape. Firstly, MEDIT i500 showed more accurate reproduction of bracket dimensions in anteriors compared to posterior regions in both the maxilla and mandible. A combination of factors may be at play, including the excess saliva in the posterior regions of the mouth and trouble stitching scanned images together owing to larger tooth surfaces. Secondly, MEDIT i500 showed more accuracy in canine bracket dimensions compared to second premolar and central incisor bracket dimensions in both the maxilla and mandible. This may be because when scanning the whole arch, the anterior area is the most challenging to scan since the incisors are long and labially inclined compared to posterior teeth.

Additionally, the labial aspect of the incisors creates an undercut from the occlusal perspective, which makes them more difficult to scan than the lingual surfaces. Consequently, data errors are likely to develop during the scan in this area. The broader lingual surfaces of the incisors, rather than the incisal edges, serve as a template for the initial scan, as occlusal surfaces do for posterior teeth[19,41]. As the second premolar was positioned more posteriorly compared to the canine, the scanner's head may be difficult to access, saliva may be excessive, or the tongue may interfere with the scanning process[41]. Another finding is that TRIOS 3 shape is unable to reproduce bracket measurements for all teeth, especially for mandibular incisors. This may be due to either difficulty capturing smaller mesiodistal dimensions of metal brackets or overlapping scanned images while stitching together.

MEDIT i500 seems to be the preferable scan over TRIOS 3 shape for surgical splint fabrication, lingual, and palatal orthodontic appliances, according to the study results, since it requires more accuracy for fabrication. Even so, there have been so many diverse scanners results that no specific intraoral scanner can be considered the best. In contrast to the buccal side of the arch, the narrow lingual side, particularly in the mandible, may greatly limit the movement of the scanner. This makes it considerably more difficult to get an accurate 3D picture if lingual brackets are bonded in this technique. For mid-orthodontic treatment scanning evaluation, controlling moisture around the brackets of teeth, and adjusting scanning direction may assist in improving the scanning accuracy of complete arch scans. Clinically, intraoral scanning helps reduce patients' major discomfort compared to plaster models, especially in mid-orthodontic treatment. However, intraoral scanning in the mouth would not have been any more difficult. The challenge is presented because of the difficulty in altering scanners' directions and angles due to the proximity of the intraoral scanner to oral structures. When scanning a complete arch for orthodontic treatment, considerable care must be taken to reduce scanning inaccuracy.

Limitations

This research has certain limitations, such as the small sample size and other potentially confounding variables, including speed, saliva, and patient mobility, which were not taken into account.

Conclusions

MEDIT i500 showed higher accuracy and better reproduction of orthodontic bracket dimensions than TRIOS 3 shape in complete arch scanning.

For quadrant arch scan in complete arch scanning, MEDIT i500 showed greater accuracy in anterior regions compared to posterior regions in both arches.

For single tooth scan in complete arch scanning, MEDIT i500 showed more accuracy in reproducing bracket dimensions for canine brackets in both the maxilla and mandible.

Hence, careful consideration is required, especially in posterior as well as mandibular arch scanning, to avoid inaccuracy in complete arch scanning for the fabrication of orthodontic appliances.

Funding
None.

Conflicts of Interest
The authors declare no conflict of interest.

Informed Consent
Since the nature of the present study was *in-vitro*, no informed consent was necessary to be obtained before study initiation.

Ethics Approval
Ethical clearance for the study protocol was obtained from the Saveetha Institutional Review Board, SIMATS University, to conduct this research (I.E.C. No: IHEC/SDC/ORHTO/-1907/22/381).

ORCID ID
Abirami. S: 0000-0002-6044-5808
Saravana Dinesh S.P: 0000-0001-5302-7483
Arvind Sivakumar: 0000-0002-5504-2262
Prasanna Arvind. T.R: 0000-0001-9087-1085
Dhalia H. Albar: 0000-0003-0250-1418
Abdulrahman Alshehri: 0000-0002-6854-8000
Wael Awad: 0000-0002-7189-4203
Khalid J. Alzahrani: 0000-0002-6688-0106
Ibrahim F. Halawani: 0000-0001-6632-0646
Saleh Alshammeri: 0000-0002-0179-0767
Hosam Ali Baeshen: 0000-0001-6422-7173
Shankargouda Patil: 0000-0001-7246-5497

Availability of Data and Materials
Data sets will be provided on request by the authors.

Authors' Contributions
Abirami- conceptualization, methodology, data analysis, original draft preparation, editing. S.P. Saravana Dinesh- conceptualization, methodology, data analysis, editing. Arvind Sivakumar- conceptualization, methodology, data analysis. Prasanna T.R.- conceptualization, methodology, original draft preparation, and editing. Dhalia H. Albar- data collection, validation, manuscript review, and editing. Abdulrahman Alshehri- data collection, validation, manuscript review, and editing. Wael Awad- supervision, manuscript review, and editing. Khalid J. Alzahrani- supervision, manuscript review, and editing. Ibrahim F. Halawani- software, data collection, editing. Saleh Alshammeri- software, data collection, editing. Hosam Ali Baeshen- software, data collection, editing. Shankargouda Patil- software, data collection, editing.

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