Accuracy of 3D Reconstructed Orthodontic Models

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Abstract

Objective: To evaluate the accuracy of 3D reconstructed orthodontic models, derived by various digitization methods, as compared to conventional orthodontic plaster models.

Materials and Methods: Twenty-five maxillary orthodontic plaster models were randomly selected from the Indiana University School of Dentistry Department of Orthodontics. Each plaster model was scanned with the Cadent iOC scanner and the digital data was used to print 3D reconstructed orthodontic models. The same 25 plaster models were duplicated using alginate and poured in plaster after two days. These duplicated plaster models were also scanned with the iOC scanner and 3D reconstructed. Next, the duplicate plaster models were sent to a lab, scanned with a 3Shape R700 scanner, and the digital data was 3D reconstructed. Digital calipers were used to obtain ten linear dimensional measurements on all plaster and 3D reconstructed models for comparisons. Equivalence testing was performed using 2 one-sided paired t-tests with a significance level of $P < 0.05$. **Results**: Nine of the 10 linear measurements were statistically equivalent in all groups. Clinically insignificant, but statistically significant, measurement differences in maxillary central incisor height ($P < 0.05$) were found on 3D reconstructed models derived from the 3Shape R700 desktop scanner. **Conclusion:** 3D reconstructed orthodontic models derived from alginate impressions, iOC scanners, and 3Shape R700 scanners are an accurate and reliable substitute for orthodontic plaster models.

Keywords: 3D models, reconstructed, accuracy, digitization, orthodontics

Introduction

Modern technology is becoming an integral part of orthodontic practice. Orthodontists are incorporating digital technology into tasks such as record keeping and treatment planning.[1] Traditionally, initial orthodontic records have included plaster study models, which are generally kept for 5 to 15 years, as endorsed by the American Association of Orthodontists.[2] However, this may pose storage problems.[3] Technological advances now provide digital models as an alternative. They have several advantages, including reduced storage space requirements, as well as improved data accessibility and transfer.[4]

Digital models can be obtained by various methods such as intraoral scanning, laser-scanning of alginate impressions, or laser-scanning of plaster models poured from alginate impressions. Taking a digital impression with an intraoral scanner is the most direct method. It uses a wand or scanning unit to capture snapshots of all teeth and of the inter-occlusal relationship.[5] Thus, a digital model can be created without an impression.

Digital orthodontic models can also be acquired indirectly by laser-scanning alginate impressions. This can be technically difficult due to the undercuts and limited space inside the alginate impression.[6] Thus, clinicians typically opt to pour a plaster model and then digitize it using one of the aforementioned digitizing techniques. Several studies have validated the accuracy of digital models when compared to plaster models.[6-10] In addition, digital orthodontic models have been shown as a valid alternative for diagnostic assessment and medical-legal record keeping.[11,12]

There are, however, situations in which physical 3-D orthodontic models are indicated, such as in appliance fabrication and for medical-legal purposes.[3] When physical orthodontic models are required, 3D reconstructed orthodontic models can be printed from digital orthodontic models using rapid prototyping (RP) technology. Stereolithography (SLA), one of the earliest forms of RP systems, was developed in the late 1980s.[13] SLA uses ultraviolet light to cure thin layers of liquid resin until a 3D physical object is fabricated. Advances in RP systems have led to the development of other reconstruction techniques, including digital light processing, jetted photopolymer and 3D printing.[14] These RP technologies are based on one common principle - the building of a 3D reconstructed object layer by layer.[15]

The accuracy of 3D reconstructed orthodontic models is less well-established than that of digital orthodontic models. In 2008, Keating *et al.* compared dimensional measurements made on one set of orthodontic plaster models with the corresponding digital models and the printed 3D reconstructed models. While they found only minimal differences between the measurements on the orthodontic plaster and digital models, they found a significant difference in crown height measurements on the plaster and the printed 3D models. These differences may be attributable to the older RP technologies.[3] In 2012, Cuperus *et al*. compared dentitions from human dry skulls to 3D reconstructed orthodontic models derived from intraoral scanning. Their results demonstrated statistically significant differences between the two groups. However, these differences were considered clinically insignificant and did not include crown height measurements.[16] In 2013, Hazeveld *et al.* compared orthodontic plaster models to 3D reconstructed models derived from different RP techniques. They found statistically significant, but clinically acceptable, differences in one of the prototyping techniques for clinical crown height measurements. [14]

Small sample sizes were significant limitations in the above described studies. Using a large sample size, our study investigated the accuracy of 3D reconstructed orthodontic models as compared to orthodontic plaster models. We also compared 3D reconstructed models derived from different digitization methods.

The specific aims of this study were to evaluate the dimensional accuracy of 3D reconstructed orthodontic models compared to conventional plaster orthodontic models, and to compare the dimensional accuracy of 3D reconstructed models generated from direct and indirect digitizing methods.

Materials and Methods

With IRB approval form the Indiana University Human Subjects Office, maxillary orthodontic plaster models were obtained for this retrospective study from the Indiana University School of Dentistry Department of Orthodontics. The samples consisted of the first 25 models from the department that met the following inclusion criteria: 1) permanent dentition, with eruption from first molar to first molar, 2) post-orthodontic treatment, 3) no missing teeth, fractures, voids, large restorations, or occlusal wear, 4) free of teeth demonstrating hypodontia, 5) no supernumerary teeth, and 6) conventionally trimmed, finished, and soaped. A total of ten linear measurements (Figure 1) were made on the 25 models using a digital caliper (Masel Co, Bristol, PA) with a ±0.01 mm accuracy (Group A). The definitions of these measurements are listed in Table 1. These measurements were considered to be the gold standard.

After measurements, each plaster model was scanned using the Cadent iOC intraoral scanner (Cadent Inc., Carlstadt, New Jersey). This was the direct method of digital data acquisition. These data were exported in a Standard Tesselation Language (STL) with OrthoCAD software (Cadent Inc., Carlstadt, New Jersey) and uploaded to the Dynaflex website. They produced 3D reconstructed orthodontic models using jetted photopolymer Polyjet technology with an Objet Eden 500V 3D printer (Objet Inc. Billerica, MA). This printer has a build resolution of 600 dots per inch (dpi) in the X and Y axes and 1600 dpi in the Z axis. Accuracy of the printer is at 20-85um. The Polyjet technology used ink-jet printing to deposit liquid photopolymer into removable build trays and then cured with ultraviolet light.[17] As with the plaster models of Group A, measurements were obtained from the printed 3D reconstructed models, Group B.

Next, impressions of the 25 original plaster models were taken using Alginmax extended storage alginate (Alginmax, Major Dental Products SpA, Moncalieri, Italy) with plastic disposable trays (G & H wire Company, Franklin, IN). This indirect method of digital data acquisition simulates a common clinical practice whereby alginate impressions are sent to an external laboratory to be poured into plaster models which are then scanned to generate digital models. Alginmax extended storage alginate was selected because of its dimensional stability required to accommodate the delay caused by shipping.[18] Each alginate impression was immediately wrapped in a wet paper towel and individually placed in a Ziploc® bag (SC Johnson Inc., Racine, WI) which were then stored in the trunk of a vehicle for two days to simulate shipping time. According to Dalstra *et al.*, this storage technique does not produce any significant impact on the quality or accuracy of plaster poured within 3 to 5 days.[6] The alginate impressions were then poured into plaster models (Whipmix Corp, Louisville, KY), soaped, and measured, Group C.

These plaster models were scanned with the Cadent iOC intraoral scanner, and as for Group B, the digital data were uploaded to the Dynaflex website to be 3D reconstructed with their Objet Eden 500V 3D printer. The measured dimensions obtained from these models constitute Group D.

The duplicated plaster models of Group C were shipped to Dynaflex for scanning by their 3Shape R700 Orthodontic 3D (3Shape, Copenhagen, Denmark) scanner. They used that data to 3D reconstruct the models with the Object Eden 500V 3D printer. Group E consisted of the measurements taken on these models.

To ensure consistency throughout the study, all 3D reconstucted models were printed by Dynaflex with their Object Eden 500V on the highest quality setting. All plaster and 3D reconstructed models were assigned random identification codes prior to data collection. One blinded investigator performed all digital caliper measurements and Cadent iOC scans. The overall study design is summarized in Figure 2.

Statistical Methods

To assess intra-examiner repeatability, dimensional measurements were recorded from five randomly selected plaster and five selected 3D reconstructed models on two separate occasions. The models were randomized and there was one week between each measurement session to avoid memory bias. The intra-class correlation coefficient (ICC) was calculated to assess intra-observer reliability and considered acceptable if ≥ 0.90.

Equivalence of the dimensional measurements between 3D reconstructed orthodontic models and conventional plaster orthodontic models, between direct and indirect methods of acquiring digital data were tested using two one-sided paired t-tests. Bland-Altman plots were also used to further evaluate the agreement between the methods. The plots included lines at +/- 0.2 mm to define the limits of agreement and the proportion of measurements within the limits were calculated.

With a sample size of 25 maxillary orthodontic plaster models, the study had 90% power to evaluate equivalence between each comparison of interest. Statistical significance was established with $P \leq 0.05$.

Results

Intra-examiner repeatability of the measurements was high, with the ICC 0.90 to 1.00 (Table 2). All five groups (Groups A through E) were considered to be equivalent for all measurements except that statistically significant differences in the maxillary right central incisor height were observed between Groups A (mean 9.86 mm) and E (mean 9.70 mm) and between Groups B (mean 9.86 mm) and E, (Table 3 and 4).

Discussion

The results demonstrate the accuracy and reproducibility of 3D reconstructed orthodontic models compared to conventional orthodontic plaster models regardless of the digitization technique (direct versus indirect and scanner type).

There are a number of studies that have considered thresholds for clinically significant measurement differences. Hirogaki *et al.* suggested that 0.3 mm is sufficient.[19] Hazeveld *et al*. recommended 0.25 mm. In the current study, the clinical significant threshold was set at 0.2 mm. However, none of these threshold would truly demonstrate clinically significant differences, due to the small magnitudes.

In the present study, all groups were considered to be equivalent except in the maxillary right central incisor heights for Groups A vs. E and B vs. E with a mean difference of 0.16 mm.

Group A models were our gold standard plaster models. Group B models, direct method, were acquired with iOC scanner of Group A and later printed into 3D reconstructed models. In our study, Group A and B were equivalent, which proved that the direct method of producing 3D reconstructed models was accurate and reliable. Group E models, derived from the indirect method, were acquired from the duplicated plaster models of Group A, scanned with a 3Shape R700 scanner, and printed into 3D reconstructed models. The mean measurement differences between Group E and those of Groups A and B were both less than 0.16 mm, which was considered to be clinically insignificant. The statistical differences in the central incisors height measurement in Group E may have resulted from the additive errors of the indirect method, such as from the combination of alginate impression shrinkage and use of the 3Shape scanner, as opposed to the iOC scanner. Although these differences were statistically significant, they were considered to be clinically insignificant. A similar observation was made by Keating *et al.*[3], who demonstrated significant measurement differences in the crown heights on plaster and 3D reconstructed models. However, at the time of that study, 3D models were printed with relatively thick layers of 0.15 mm resin[3] as opposed to the current 0.016 mm.[17]

Due to the high cost of intraoral scanners, some clinicians elect to take an alginate impression and send it via postal service to a company specializing in digital orthodontic models. Because of the dimensional instability of traditional alginate impressions[20] we used "extended-storage" alginate.[21] There was no significant differences between the original plaster models (Group A) and the plaster models poured two days later from extended-storage alginate impression (Group C) Therefore, accurate duplication of plaster models can be produced when using Algimax extended-storage alginate with proper packaging protocol. Our alginate impressions were stored in the trunk of a car in Indianapolis, where temperatures ranged from 46 degrees to 70 degrees Fahrenheit.[22] However, clinicians need to be aware that considerable dimensional changes to alginate impressions can occur when subjected to extreme hot or cold temperatures.[20]

There were several limitations in this study. First, the majority of clinicians use the iOC scanner for intraoral scanning, not for extraoral scanning of plaster models. According to Flugge *et al.*, intraoral scans are complicated by saliva and limited space, making it much more difficult to achieve accurate scanning when compared to extraoral scanning, as was done in the current study. They found the mean deviation for an intraoral iOC scan was 0.050 mm versus 0.025 mm for an extraoral scan.[23] Despite the challenges of direct intraoral scanning, a 0.025 mm discrepancy is considered to be clinically insignificant. Another limitation of our study was the use of only post-treatment maxillary orthodontic models. While this design simplified model assessment, it does not fully replicate all clinical situations. Dentitions containing severely malposed teeth may be slightly more difficult to reproduce using the techniques mentioned in this study. But the authors feel that this is a minor limitation and does not compromise the equivalence observed between plaster and 3D reconstructed orthodontic models.

Conclusion

- 3D reconstructed orthodontic models are accurate when compared to conventional plaster orthodontic models.
- No clinically significant differences were found between 3D reconstructed orthodontic models derived from direct and indirect digitization methods.

- Clinically insignificant, but statistically significant, measurement differences in crown height were found on 3D reconstructed orthodontic models derived from the 3Shape R700 desktop scanner.
- Extended-storage alginate impression material can produce accurate plaster and 3D reconstructed orthodontic models even after two days.

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Figures and Tables Legend

Figure 1. Examples of linear measurements on orthodontic models.

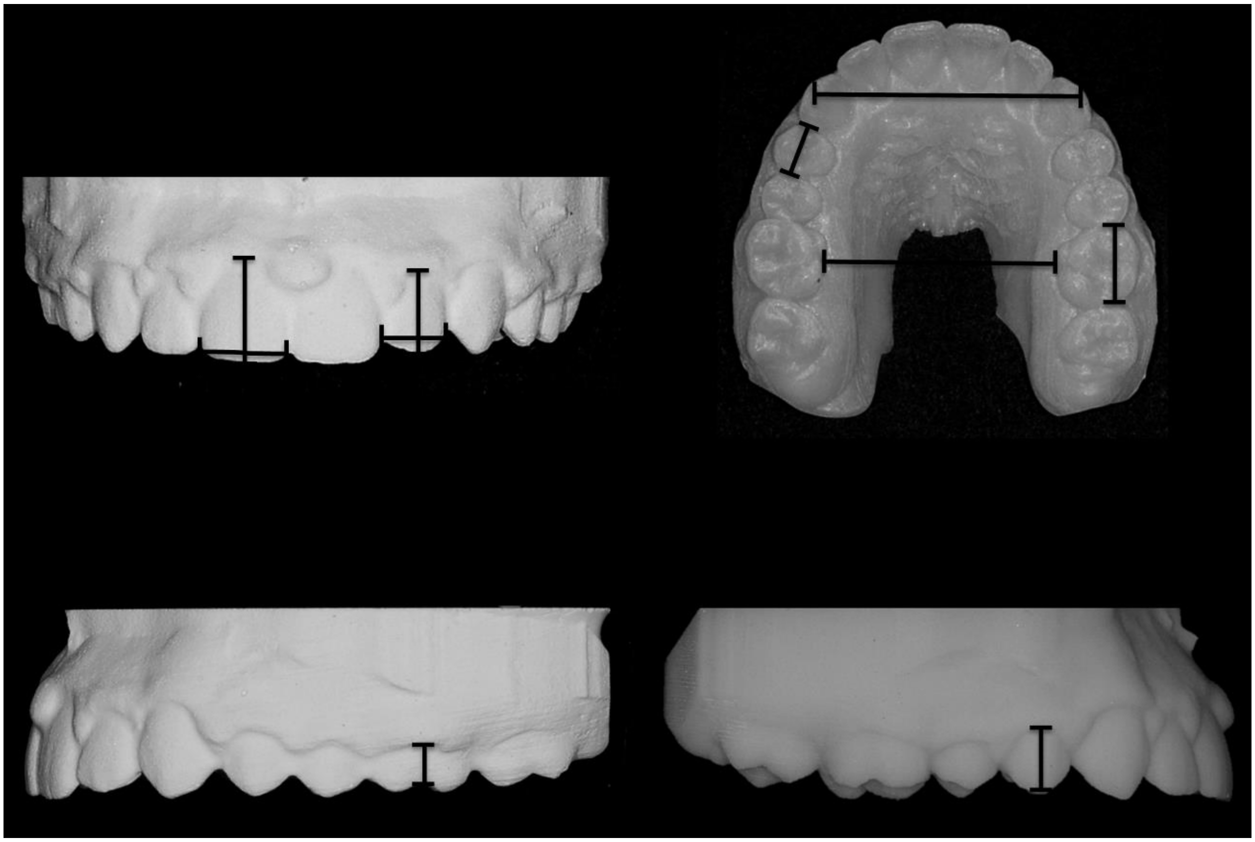
Figure 2. Overview of study design. Linear measurements are made in the bolded boxes.

Table 1. Definitions of linear measurements.

Table 2. Intra-observer reproducibility with ICC values.

Table 3. Mean (SE) for each measurement by group.

Table 4. Mean differences between groups for each measurement parameter.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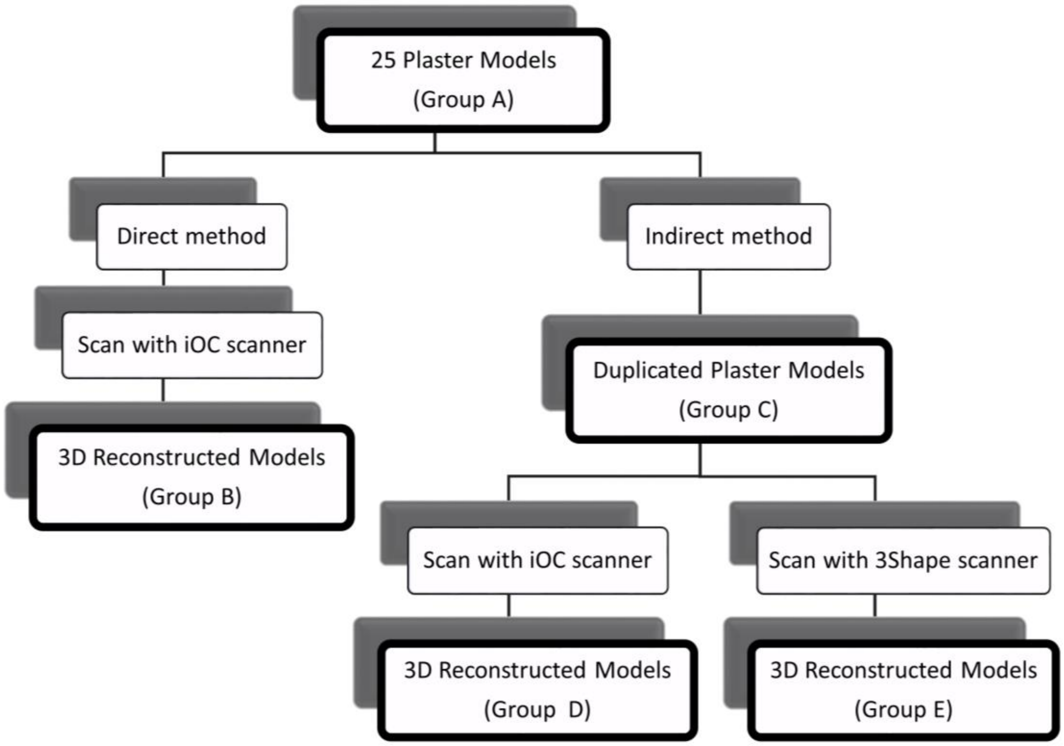

Figure 2. Overview of study design. Linear measurements are made in the bolded boxes.

Table 2. Definitions of linear measurements.

Maxillary inter-canine width	Measured distance from the cusp tip of left maxillary canine to the cusp tip of right maxillary canine as viewed from the occlusal surface.
Maxillary inter-molar width	Measured distance from the most cervical point of lingual groove of left 1st maxillary molar to the most cervical point of lingual groove of right 1st maxillary molar.
Maxillary right central incisor height	Measured from a point of maximum concavity of the labial gingival margin to the incisal edge of the maxillary right central incisor.
Maxillary right central incisor width	Measured distance between the mesial and distal anatomical contact as viewed from the occlusal surface of the maxillary right central incisor.
Maxillary left lateral incisor height	Measured from a point of maximum concavity of the labial gingival margin to the incisal edge of the maxillary left lateral incisor.
Maxillary left lateral incisor width	Measured distance between the mesial and distal anatomical contacts as viewed from the occlusal surface of the maxillary left lateral incisor.
Maxillary right 1st premolar height	Measured from a point of maximum concavity of the labial gingival margin to the bucco-occlusal tip of the maxillary right 1st premolar.
Maxillary right 1st premolar width	Measured distance between the mesial and distal anatomical contacts as viewed from the occlusal surface of the maxillary right 1st premolar.
Maxillary left 1st molar height	Measured from a point of maximum concavity of the labial gingival margin to the tip of the buccal groove of the maxillary left 1st molar.
Maxillary left 1st molar width	Measured distance between the mesial and distal anatomical contacts as viewed from the occlusal surface of the maxillary left 1st molar.

Table 2. Intra-observer reproducibility with ICC values.

	Measurement	Difference between 1st and 2nd measurement Mean (SE)	Min	Max	p-value	ICC
All	Maxillary inter-canine width	0.00 (0.02)	-0.09	0.09	0.85	1.00
	Maxillary inter-molar width	0.01 (0.02)	-0.12	0.07	0.81	1.00
	Maxillary right central incisor height	-0.01 (0.02)	-0.09	0.07	0.52	1.00
	Maxillary right central incisor width	-0.02 (0.02)	-0.1	0.08	0.27	0.99
	Maxillary left lateral incisor height	-0.02 (0.02)	-0.14	0.11	0.43	1.00
	Maxillary left lateral incisor width	0.03 (0.02)	-0.07	0.13	0.25	0.99
	Maxillary right 1st premolar height	0.02 (0.02)	-0.07	0.11	0.30	1.00
	Maxillary right 1st premolar width	0.00 (0.02)	-0.09	0.13	0.96	0.99
	Maxillary left 1st molar height	0.02 (0.01)	-0.04	0.08	0.22	1.00
	Maxillary left 1st molar width	0.05 (0.06)	-0.08	0.53	0.37	0.95
Plaster	Maxillary inter-canine width	0.00 (0.03)	-0.09	0.09	0.95	1.00
	Maxillary inter-molar width	0.02 (0.03)	-0.08	0.07	0.52	1.00
	Maxillary right central incisor height	0.02 (0.03)	-0.06	0.07	0.57	1.00
	Maxillary right central incisor width	-0.03 (0.03)	-0.1	0.07	0.31	0.99
	Maxillary left lateral incisor height	-0.02 (0.01)	-0.04	0	0.05	1.00
	Maxillary left lateral incisor width	0.00 (0.03)	-0.07	0.08	1.00	0.99
	Maxillary right 1st premolar height	0.04 (0.04)	-0.07	0.11	0.36	0.99
	Maxillary right 1st premolar width	-0.04 (0.02)	-0.09	0.01	0.10	0.98
	Maxillary left 1st molar height	0.03 (0.02)	-0.01	0.08	0.15	1.00
	Maxillary left 1st molar width	0.02 (0.02)	-0.05	0.07	0.32	1.00
Reconstructed	Maxillary inter-canine width	0.01 (0.03)	-0.07	0.07	0.74	1.00
	Maxillary inter-molar width	-0.01 (0.03)	-0.12	0.06	0.76	1.00
	Maxillary right central incisor height	-0.04 (0.03)	-0.09	0.04	0.17	0.99
	Maxillary right central incisor width	-0.01 (0.03)	-0.1	0.08	0.70	0.93
	Maxillary left lateral incisor height	-0.02 (0.05)	-0.14	0.11	0.72	0.99
	Maxillary left lateral incisor width	0.05 (0.03)	0	0.13	0.14	0.99
	Maxillary right 1st premolar height	0.01 (0.03)	-0.05	0.09	0.72	0.99
	Maxillary right 1st premolar width	0.03 (0.03)	-0.04	0.13	0.29	0.99
	Maxillary left 1st molar height	0.00 (0.01)	-0.04	0.05	1.00	1.00
	Maxillary left 1st molar width	0.08 (0.11)	-0.08	0.53	0.52	0.90

ICC indicates intraclass correlation coefficient.

Table 3. Mean (SE) for each measurement by group.

Measurement	A	B	C	D	E
Maxillary inter-canine width	35.12 (0.43)	35.15 (0.42)	35.09 (0.43)	35.11 (0.43)	35.08 (0.43)
Maxillary inter-molar width	33.97 (0.58)	33.98 (0.58)	33.91 (0.57)	33.93 (0.57)	33.87 (0.57)
Maxillary left 1st molar height	5.00 (0.18)	4.98 (0.18)	5.00 (0.18)	4.99 (0.18)	4.99 (0.17)
Maxillary left 1st molar width	10.27 (0.10)	10.28 (0.10)	10.24 (0.10)	10.25 (0.10)	10.24 (0.10)
Maxillary left lateral incisor height	8.27 (0.24)	8.26 (0.24)	8.18 (0.24)	8.15 (0.25)	8.14 (0.24)
Maxillary left lateral incisor width	7.36 (0.12)	7.40 (0.12)	7.36 (0.12)	7.38 (0.12)	7.39 (0.12)
Maxillary right 1st premolar height	6.92 (0.22)	6.92 (0.22)	6.88 (0.22)	6.86 (0.22)	6.88 (0.22)
Maxillary right 1st premolar width	7.11 (0.08)	7.14 (0.07)	7.11 (0.08)	7.15 (0.08)	7.15 (0.08)
Maxillary right central incisor width	9.27 (0.13)	9.31 (0.13)	9.27 (0.13)	9.30 (0.14)	9.31 (0.14)
Maxillary right central incisor height	9.86 (0.22)*****	9.86 (0.23)*****	9.74 (0.22)	9.74 (0.22)	9.70 (0.22)*****

*****$P \leq 0.05$

Table 4. Mean differences between groups for each measurement parameter.

Measurement	Comparison	Mean (95% CI)	Min	Max	Nonequivalent
Maxillary inter-canine width	A vs. B	-0.02 (-0.05, 0.00)	-0.12	0.14	
	A vs. C	0.03 (0.01, 0.05)	-0.10	0.13	
	A vs. D	0.02 (-0.01, 0.05)	-0.12	0.14	
	A vs. E	0.04 (0.01, 0.07)	-0.05	0.19	
	B vs. C	0.05 (0.02, 0.09)	-0.14	0.15	
	B vs. D	0.04 (0.01, 0.07)	-0.11	0.18	
	B vs. E	0.06 (0.03, 0.10)	-0.11	0.22	
	C vs. D	-0.01 (-0.03, 0.01)	-0.11	0.08	
	C vs. E	0.01 (-0.01, 0.03)	-0.07	0.07	
	D vs. E	0.02 (0.00, 0.05)	-0.10	0.15	
Maxillary inter-molar width	A vs. B	-0.01 (-0.03, 0.01)	-0.13	0.07	
	A vs. C	0.05 (0.01, 0.09)	-0.08	0.30	
	A vs. D	0.04 (-0.01, 0.08)	-0.18	0.31	
	A vs. E	0.10 (0.05, 0.15)	-0.05	0.33	
	B vs. C	0.06 (0.02, 0.10)	-0.08	0.33	
	B vs. D	0.05 (0.00, 0.09)	-0.13	0.34	
	B vs. E	0.11 (0.07, 0.15)	-0.06	0.36	
	C vs. D	-0.02 (-0.04, 0.01)	-0.22	0.08	
	C vs. E	0.05 (0.02, 0.08)	-0.03	0.32	
	D vs. E	0.06 (0.03, 0.10)	-0.04	0.26	
Maxillary right central incisor width	A vs. B	-0.04 (-0.06, -0.03)	-0.17	0.04	
	A vs. C	0.00 (-0.02, 0.02)	-0.07	0.11	
	A vs. D	-0.04 (-0.06, -0.01)	-0.14	0.09	
	A vs. E	-0.04 (-0.07, -0.01)	-0.18	0.10	
	B vs. C	0.04 (0.02, 0.07)	-0.06	0.19	
	B vs. D	0.01 (-0.02, 0.04)	-0.09	0.17	
	B vs. E	0.00 (-0.03, 0.04)	-0.17	0.17	
	C vs. D	-0.03 (-0.05, -0.02)	-0.12	0.03	
	C vs. E	-0.04 (-0.06, -0.02)	-0.14	0.05	
	D vs. E	-0.01 (-0.02, 0.01)	-0.08	0.06	
Maxillary right central incisor height	A vs. B	0.00 (-0.01, 0.01)	-0.06	0.07	
	A vs. C	0.12 (0.08, 0.16)	-0.04	0.37	
	A vs. D	0.12 (0.08, 0.15)	-0.06	0.42	
	A vs. E	0.16 (0.12, 0.20)	-0.09	0.42	*
	B vs. C	0.12 (0.07, 0.16)	-0.04	0.41	
	B vs. D	0.12 (0.07, 0.16)	-0.06	0.46	
	B vs. E	0.16 (0.11, 0.21)	-0.08	0.48	*
	C vs. D	0.00 (-0.02, 0.02)	-0.13	0.06	
	C vs. E	0.05 (0.03, 0.07)	-0.06	0.13	
	D vs. E	0.05 (0.01, 0.08)	-0.10	0.22	
Maxillary left lateral incisor height	A vs. B	0.01 (-0.01, 0.03)	-0.07	0.14	
	A vs. C	0.09 (0.06, 0.13)	-0.07	0.31	
	A vs. D	0.12 (0.08, 0.16)	-0.11	0.32	
	A vs. E	0.13 (0.09, 0.17)	-0.02	0.32	
	B vs. C	0.08 (0.05, 0.12)	-0.07	0.26	
	B vs. D	0.11 (0.07, 0.15)	-0.06	0.27	

	B vs. E	0.12 (0.08, 0.16)	-0.04	0.35	
	C vs. D	0.03 (0.01, 0.05)	-0.05	0.11	
	C vs. E	0.04 (0.01, 0.07)	-0.10	0.18	
	D vs. E	0.01 (-0.02, 0.04)	-0.17	0.15	
Maxillary left lateral incisor width	A vs. B	-0.04 (-0.06, -0.02)	-0.13	0.05	
	A vs. C	0.00 (-0.02, 0.01)	-0.05	0.08	
	A vs. D	-0.03 (-0.05, 0.00)	-0.22	0.09	
	A vs. E	-0.03 (-0.05, -0.01)	-0.11	0.08	
	B vs. C	0.04 (0.02, 0.06)	-0.07	0.12	
	B vs. D	0.01 (-0.01, 0.04)	-0.11	0.12	
	B vs. E	0.01 (-0.02, 0.03)	-0.10	0.11	
	C vs. D	-0.02 (-0.05, 0.00)	-0.17	0.06	
	C vs. E	-0.03 (-0.05, -0.01)	-0.12	0.08	
	D vs. E	-0.01 (-0.04, 0.02)	-0.13	0.16	
Maxillary right 1st premolar height	A vs. B	0.00 (-0.02, 0.02)	-0.09	0.13	
	A vs. C	0.04 (0.02, 0.06)	-0.06	0.11	
	A vs. D	0.06 (0.02, 0.09)	-0.08	0.41	
	A vs. E	0.04 (0.02, 0.07)	-0.07	0.15	
	B vs. C	0.04 (0.02, 0.07)	-0.05	0.20	
	B vs. D	0.06 (0.02, 0.10)	-0.08	0.43	
	B vs. E	0.05 (0.01, 0.08)	-0.09	0.17	
	C vs. D	0.02 (-0.02, 0.05)	-0.05	0.33	
	C vs. E	0.00 (-0.02, 0.02)	-0.08	0.08	
	D vs. E	-0.01 (-0.04, 0.02)	-0.26	0.09	
Maxillary right 1st premolar width	A vs. B	-0.04 (-0.06, -0.01)	-0.15	0.05	
	A vs. C	0.00 (-0.02, 0.02)	-0.11	0.08	
	A vs. D	-0.04 (-0.06, -0.03)	-0.13	0.01	
	A vs. E	-0.04 (-0.06, -0.02)	-0.14	0.13	
	B vs. C	0.03 (0.02, 0.05)	-0.04	0.10	
	B vs. D	-0.01 (-0.03, 0.01)	-0.08	0.08	
	B vs. E	0.00 (-0.03, 0.02)	-0.11	0.11	
	C vs. D	-0.04 (-0.06, -0.03)	-0.15	0.04	
	C vs. E	-0.04 (-0.06, -0.02)	-0.12	0.05	
	D vs. E	0.00 (-0.02, 0.03)	-0.15	0.13	
Maxillary left 1st molar height	A vs. B	0.02 (0.01, 0.04)	-0.04	0.11	
	A vs. C	0.00 (-0.03, 0.02)	-0.13	0.13	
	A vs. D	0.01 (-0.02, 0.04)	-0.15	0.15	
	A vs. E	0.01 (-0.03, 0.05)	-0.15	0.17	
	B vs. C	-0.02 (-0.05, 0.00)	-0.10	0.08	
	B vs. D	-0.02 (-0.04, 0.01)	-0.19	0.17	
	B vs. E	-0.01 (-0.04, 0.02)	-0.17	0.12	
	C vs. D	0.01 (-0.01, 0.02)	-0.11	0.09	
	C vs. E	0.01 (-0.01, 0.03)	-0.11	0.12	
	D vs. E	0.00 (-0.02, 0.03)	-0.12	0.13	
Maxillary left 1st molar width	A vs. B	-0.02 (-0.03, -0.01)	-0.09	0.04	
	A vs. C	0.02 (0.01, 0.04)	-0.03	0.11	
	A vs. D	0.02 (0.00, 0.04)	-0.05	0.11	
	A vs. E	0.03 (-0.02, 0.08)	-0.06	0.59	

	B vs. C	0.04 (0.03, 0.06)	-0.04	0.13	
	B vs. D	0.04 (0.02, 0.06)	-0.08	0.13	
	B vs. E	0.05 (0.00, 0.10)	-0.05	0.56	
	C vs. D	-0.01 (-0.02, 0.01)	-0.04	0.06	
	C vs. E	0.00 (-0.04, 0.05)	-0.05	0.49	
	D vs. E	0.01 (-0.03, 0.05)	-0.09	0.48	