

# Correlation and agreement of a digital and conventional method to measure arch parameters

## Korrelation und Übereinstimmung von digitaler und konventioneller Bestimmung von Zahnbogenparametern

Nes Nawi<sup>1,3</sup> · Alizae Marny Mohamed<sup>1</sup> · Murshida Marizan Nor<sup>1</sup> · Nor Atika Ashar<sup>2</sup>

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### Abstract

**Objective** The aim of the present study was to determine the overall reliability and validity of arch parameters measured digitally compared to conventional measurement.

**Methods** A sample of 111 plaster study models of Down syndrome (DS) patients were digitized using a blue light three-dimensional (3D) scanner. Digital and manual measurements of defined parameters were performed using Geomagic analysis software (Geomagic Studio 2014 software, 3D Systems, Rock Hill, SC, USA) on digital models and with a digital calliper (Tuten, Germany) on plaster study models. Both measurements were repeated twice to validate the intraexaminer reliability based on intraclass correlation coefficients (ICCs) using the independent *t* test and Pearson's correlation, respectively. The Bland–Altman method of analysis was used to evaluate the agreement of the measurement between the digital and plaster models.

**Results** No statistically significant differences ( $p > 0.05$ ) were found between the manual and digital methods when measuring the arch width, arch length, and space analysis. In addition, all parameters showed a significant correlation coefficient ( $r \geq 0.972$ ;  $p < 0.01$ ) between all digital and manual measurements. Furthermore, a positive agreement

between digital and manual measurements of the arch width (90–96%), arch length and space analysis (95–99%) were also distinguished using the Bland–Altman method.

**Conclusion** These results demonstrate that 3D blue light scanning and measurement software are able to precisely produce 3D digital model and measure arch width, arch length, and space analysis. The 3D digital model is valid to be used in various clinical applications.

**Keywords** Manual measurement · Digital measurement · Blue light 3D scanner · Down syndrome

### Zusammenfassung

**Zielsetzung** Ziel der vorgestellten Studie war es, Reliabilität und Validität digitaler Messungen von Bogenparametern im Vergleich zu konventionellen Messungen zu ermitteln.

**Methoden** Insgesamt 111 Gipsmodelle von Down-Syndrom-Patienten wurden mit einem auf Blaulichttechnologie basierenden 3-D-Scanner digitalisiert. Anschließend wurden digitale (Geomagic Studio 2014 Software; 3D Systems, Rock Hill/SC, USA) und manuelle (digitale Schieblehre; Tuten, Deutschland) Messungen definierter Parameter an digitalen Modellen und Gipsmodellen vorgenommen. Alle Messungen wurden zweimal wiederholt, um auf Grundlage der Intraklassenkoeffizienten die Intrauntersucherreliabilität zu validieren. Zur statistischen Auswertung dienten der unabhängige Student-*t*-Test und der Pearson-Korrelationskoeffizient, der Bland–Altman-Test zur Evaluierung der Übereinstimmung zwischen den Messungen an digitalen bzw. an Gipsmodellen.

**Ergebnisse** Bei der Messung von Länge und Breite der Kieferbögen sowie bei der Platzanalyse wurden keine statistisch signifikanten Unterschiede ermittelt ( $p > 0,05$ ). Zudem zeigten sich für alle Parameter signifikante

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Dr. Alizae Marny Mohamed.

✉ Alizae Marny Mohamed  
alizaeamary@gmail.com

<sup>1</sup> Department of Orthodontics, Faculty of Dentistry, Universiti Kebangsaan Malaysia, Jalan Raja Muda Abd Aziz, 50300 Kuala Lumpur, Malaysia

<sup>2</sup> Department of Clinical Oral Biology, Faculty of Dentistry, Universiti Kebangsaan Malaysia, Kuala Lumpur, Malaysia

<sup>3</sup> Ministry of Health, Sarawak, Malaysia

Korrelationskoeffizienten ( $r \geq 0,972$ ;  $p < 0,01$ ) zwischen digitalen und manuellen Messungen. Weiterhin bestand nach Einsatz der Bland–Altman-Methode eine positive Übereinstimmung zwischen digitalen und manuellen Messungen der Breite (90–96%) und Länge der Kieferbögen sowie der Platzanalyse (95–99%).

**Schlussfolgerung** Die vorgestellten Ergebnisse zeigen, dass mit 3-D-Blaulicht-Scanning und einer Mess-Software digitale 3-D-Modelle präzise erstellt werden können, sich Kieferbögen in Länge wie Breite genau vermessen und sich die Platzverhältnisse präzise analysieren lassen. Damit ist das digitale 3-D-Modell für unterschiedliche klinische Anwendungen validiert.

**Schlüsselwörter** Digitale Messung · Manuelle Messung · 3-D-Blaulicht-Scanner · Down-Syndrom

## Introduction

Plaster models are an essential tool in orthodontic diagnosis, monitoring treatment progress, and part of patients' record. Recent advancements in technology have led to the development of three-dimensional (3D) digital models, which are used in orthodontic offices and institutions as an alternative to plaster models [13, 22, 31]. Plaster models are prone to degradation and breakage, whereas 3D digital models are more appealing to practitioners due to their simplicity with regard to storage and retrieval, maintenance, and rapid access of data. Furthermore, practitioners are able to analyze digital models and instantly formulate treatment planning [21, 25, 33].

Digital models are generated by scanning plaster study models [6, 11, 24, 29] or impressions of the arch [17, 32]. Digital models were also successfully produced using CT data [7] and cone beam computer tomography (CBCT) records [3, 13]. An ideal digital model must enable the practitioner to view and measure it like a conventional plaster model. Therefore, evidence of reliability and validity of 3D digital models is essential in order for 3D digital models to fully replace plaster models. Previous studies have shown positive reliable measurements of tooth size, arch length, space analysis, overjet, and overbite. Furthermore, the Bolton ratio can also be attained when conventional plaster models are compared to digital models [8, 11, 15, 18, 29]. Despite these promising results, further investigation is required when examining and comparing digital models' surface characteristics because an unreliable and invalid sight and measurement may lead to adverse clinical errors. Hence, complicated measurements such as arch length, arch width, and the amount of space available between conventional and digital models must be

highlighted and observed, even though some degree of error in the measurement is viewed as clinically acceptable.

In addition, a steady positive reception of the 3D digital models in orthodontics initiated rapid technological advancement. Manufacturers have continuously introduced new scanners and software using different scanning techniques and 3D volume or any spatial relation to it, to generate digital models [12, 13, 21, 28]. Therefore, calibration of handling technique is crucial to avoid operator and material errors. In addition, the different types of available software might also account for differences between plaster and digital models [3, 14].

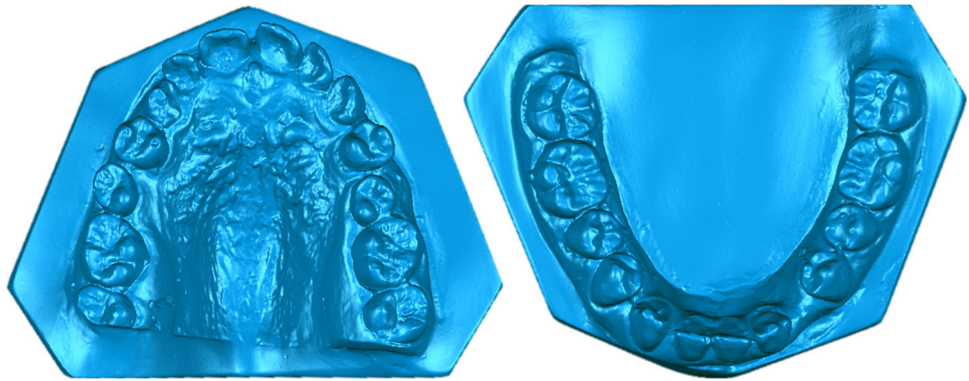
The light technology of the 3D scanner can be divided into laser light (Ortho Insight 3D<sup>TM</sup>, 3Shape R500<sup>TM</sup>, and R700<sup>TM</sup> scanner, Minolta Vivid 900 scanner), white light (d-Station3D white light scanner), and blue light technology (Atos 3D scanner, 3Shape R900<sup>TM</sup> scanner). The blue light scanner notably is one of the latest scanners available on the market, designed to analyze images and refine clinicians' operational skills to produce an accurate imaging system. When comparing these three modes of light, the blue light technology is recognized to have a longer lasting light source that is safe to the eyes and can be used in a well-lit room while filtering out other sources of light. In addition, it uses less energy compared to its predecessors due to its low current densities.

Individuals with Down syndrome (DS) or trisomy 21, notably a syndrome exhibiting high prevalence of malocclusion, require special orthodontic care and treatment [1, 16, 20]. In general, DS individuals frequently present crowding, displacements of teeth, impacted teeth, and retained deciduous teeth. Therefore, the analysis of study models of DS patients is a demanding task for the orthodontist. For this reason, the aim of this study is to determine the reliability and validity of the arch width, length and space analysis measurements of 3D digital models compared to manual measurement of plaster models in DS patients.

## Materials and methods

Ethical approval was obtained from the Ethics Committee [1.5.3.5/244/DD/2014/050(1)]. A total of 111 plaster study models of DS patients from a previous study [1] were included in the study. The sample size was determined using an online sample size calculator [9]. The parameters of the study were determined using the probability proportional to population size method with a power of 80% and a sampling error set at 5%. The inclusion criteria were as follows: teeth displaying no visible attrition and restoration, which may affect the mesiodistal or buccal–

**Fig. 1** Final three-dimensional images of digital models  
**Abb. 1** Endgültige dreidimensionale Darstellungen der digitalen Modelle



lingual diameter of the crown; no teeth fractures on the plaster study models.

Rexcan CS+ (Solutionix Corp., Seoul, Korea) is a 3D scanner adopting twin camera technology and utilizing the highest-grade scanners. It is able to acquire high-resolution data using Solutionix's exclusive multiple-strip pattern, blue light emitting diode (LED) technology, and high-resolution camera. In addition, its high-precision lenses offer feature precision and surface noise of 10  $\mu\text{m}$  or lower. The feature is further enhanced with blue light sensor, which enables it to acquire precise and detailed data. The heart of its operation is the Ezscan7 software, which has the capacity to handle more than 100-million point data and supports real-time data compression, rendering function (sampling) to maintain the quality of the measured data.

Prior to every scanning process, sensor and axis calibration were performed following the manufacturer's guidelines to calculate the relative positional parameter between the scanner's light source and the camera. The plaster model was placed and positioned within the scanning area on a pedestal (TA-300 stand) that moves on two axes (swing and rotation). The scanning area was set at 180 widths  $\times$  145 heights  $\times$  235 diagonals. Then, the camera brightness was inspected to ensure that the image of plaster model was not too bright or too dark. This was done to avoid image distortion that could potentially result in the image being discarded. During this process, any dark area on the plaster model was coated with powder spray to achieve the correct brightness. The plaster model was scanned on the TA-300 stand according to the predetermined angle. This produced multiple clouds of images of the digital model. The scanning procedure lasted approximately 15 min for one model. Then, unwanted clouds of images were deleted, while remaining clouds were aligned and merged to produce a 3D image of the digital model. These data were then saved in a stereolithographic (STL) file format and exported into the Geomagic Studio 2014 software (3D Systems, Rock Hill, SC, USA). The 3D images were further cleaned, reconstructed and any missing areas were reproduced using Geomagic software to produce the final 3D image of the digital model (Fig. 1).

The following two measuring techniques were used: manually using digital callipers (Tuten, Germany) where the pointed peak was placed parallel to the long axis of the tooth [26] and digitally using the built-in tools in the Geomagic software. The images were first enlarged to 200% on the screen using a magnifying tool for accuracy and ease of measurement. Measurements were then made both on the maxillary and mandibular models, which were performed to the nearest 0.01 mm. The variables measured are shown in Table 1.

Prior to actual measurement, an intraexaminer reliability test was carried out where 20 sets of plaster models and digital models were randomly selected and measured using manual and digital measurements. The models were remeasured manually and digitally at a 2-week interval. Then, data were analyzed using intraclass correlation coefficients (ICC). The method error was also evaluated by rescanning the same 20 plaster model into digital models. Measurements from the first and second scanning were also analyzed statistically using ICC.

All data were analyzed using the Statistical Package for Social Sciences (SPSS) Version 22 (International Business Machine Corporation, 2013). In addition, the data distribution was analyzed using the Shapiro–Wilk normality test and all data were normally distributed ( $p > 0.05$ ). The significant differences between the mean of manual measurements (digital calliper) and digital measurements (Geomagic Software) were established using independent  $t$  test. The mean rank and standard deviation of all variables were calculated. Then, the bivariate (Pearson) coefficient of correlation ( $r$ ) was used to determine the correlation and Bland–Altman analysis was used to evaluate the agreement between digital and manual measurements, respectively.

## Results

The ICCs of all variables for both manual and digital measurements were  $> 0.868$  (Table 2). In addition, the ICCs between the first and second measurements of the

**Tab. 1** Variables measured  
**Tab. 1** Vermessene Variablen

Variable	Parameter description
Mesiodistal width	Teeth from the first molar (M1) to the first molar (M1) on the other side of the arch; the greatest mesiodistal diameter from anatomical mesial contact point to the anatomical distal contact point of each tooth [10]
Transverse dimension	Inter canine width—the distance between the crown tip of the permanent canine Interfirst premolar (PM1) width and intersecond premolar (PM2) width—the distance between the buccal cusp tips of the first premolar/second premolar teeth Interfirst molar (M1) width—the distance between the mesio-buccal cusp tips of the M1 [22]
Arch length	Measured by the segment arch approach [22] A: The distance from the mesial contact point of the right M1 to the mesial contact point of the right canine B: The distance from the mesial contact point of the canine to the mesial point of the right central incisor C: The distance from mesial contact point the left I1 to the mesial contact point of the left canine D: The distance from the mesial contact point of the left canine to the mesial contact point of the left first molar Arch length was then determined through the summation of the maxillary and mandibular arch length segments which is the total amount of the segments (A + B+C + D). Under some circumstances, some adjustments were made as follows: In the dentition with missing PM2 and M1, the arch length was measured from the right PM1 to the left PM1 In the dentition with missing PM1, the arch length was measured from the distal contact point of the most distal teeth that was present in the arch to the distal contact point of the most distal teeth that was present on the other side of the arch In the dentition with spacing on the anterior teeth and median diastema, the arch length was measured from the mesial contact point of the right M1 to the mesial contact point right canine (Segment A), from mesial contact point of the right canine to the mesial contact point of the right I1 (Segment B), from mesial contact point of the right I1 to the mesial contact point of the left canine (Segment C) and from mesial contact point of the left canine to the mesial contact point of the left M1 (Segment D)
Space needed	Summation of the mesiodistal width of the right and left teeth of the arch [22]
Space analysis	Arch length—space needed

**Tab. 2** Intraclass coefficients (ICC) for repeated measurements (intraexaminer reliability)  
**Tab. 2** Intraklassenkoeffiziente (ICC) für wiederholte Messungen (Intra-Untersucher-Reliabilität)

Measurement parameter	Mesiodistal width	Transverse	Arch length
A			
Manual	0.868–0.997	0.956–1.00	0.981–1.00
Digital	0.982–1.00	0.998–1.00	0.998–1.00
B			
Digital	0.960–0.999	0.918–1.00	0.988–0.989

A re-measured, B rescanned and re-measured

digital models were  $> 0.918$  (Table 2). This finding suggests a good positive agreement between the manual and digital measurement as well as between both digital measurements, hence, suggesting good intraexaminer reliability.

Table 3 shows that there were no significant differences ( $p > 0.05$ ) in the arch width, arch length, and space analysis when compared between manual and digital measurements. In addition, the Pearson correlation also showed strong and positive correlations ( $r > 0.970$ ) between the manual and digital measurements. The Bland–Altman analysis showed that the mean difference of all variables for maxillary and mandibular arch were between  $-0.09$  and  $0.13$  (Table 4) and all variables showed a small range of 95% limit of agreement. However, mandibular arch

length and space analysis were  $\geq 95\%$  limit of agreement of between  $-2.78$  and  $2.63$  and between  $-2.45$  and  $2.00$ , respectively (Table 4, Fig. 2).

## Discussion

To date, the plaster model is still the preferred method used for clinical diagnosis, treatment planning, and evaluation of treatment progress. However, current advanced technologies in computer systems and cutting-edge scanning technologies are now able to produce 3D digital models. Some of the imaging technologies have short scanning duration and can produce an exceptionally accurate 3D digital model. This can facilitate the clinician in managing

**Tab. 3** Mean and bivariate (Pearson) correlation of maxillary and mandibular arch measurements

**Tab. 3** Mittlere und bivariate (Pearson) Korrelation der Bogenmessungen in Ober- und Unterkiefer

Arch	Measurement	Mean (standard deviation)		p value	Pearson's correlation (r)
		Caliper	Digital		
Maxilla	IC	28.87 (3.94)	29.00 (3.80)	0.78	0.998**
	IPM1	37.64 (3.58)	37.60 (3.56)	0.94	0.997**
	IPM2	43.09 (4.10)	43.07 (4.11)	0.97	1.000**
	IM1	46.28 (4.50)	46.29 (4.48)	0.99	0.997**
	Arch length	64.72 (7.25)	64.27 (7.24)	1.00	0.997**
	Space analysis	4.45 (9.72)	4.32 (9.80)	0.92	0.997**
Mandibular	IC	23.82 (4.06)	23.92 (4.01)	0.87	0.997**
	IPM1	32.79 (3.85)	32.89 (3.73)	0.87	0.999**
	IPM2	39.98 (3.57)	39.96 (3.60)	0.98	1.000**
	IM1	45.46 (4.41)	45.49 (4.32)	0.97	0.996**
	Arch length	59.82 (5.75)	59.75 (5.82)	0.92	0.972**
	Space analysis	4.98 (6.12)	4.95 (6.10)	0.97	0.978**

IC intercanine, IPM1 interfirst premolar, IPM2 intersecond premolar, IM1 interfirst molar

\*p < 0.05; \*\*p < 0.01

**Tab. 4** Bland–Altman analysis of digital and calliper measurements of the maxillary and mandibular arch

**Tab. 4** Bland–Altman-Analyse der Bogenmessungen in Ober- und Unterkiefer

Arch	Measurement	Mean difference	CI (95%)		Bland–Altman agreement (%)
			Lower limit	Upper limit	
Maxilla	IC	− 0.09	− 0.56	0.38	93
	IPM1	0.05	− 0.49	0.58	96
	IPM2	0.02	− 0.15	0.19	91
	IM1	− 0.05	− 0.76	0.66	93
	Arch length	− 0.00	− 1.00	1.00	95
	Space analysis	0.13	− 1.47	1.73	95
Mandibular	IC	0.06	− 0.67	0.54	90
	IPM1	0.00	− 0.26	0.25	94
	IPM2	0.00	− 0.19	0.17	93
	IM1	0.07	− 0.89	0.74	91
	Arch length	0.07	− 2.78	2.63	99
	Space analysis	0.03	− 2.45	2.00	99

CI confidence interval, IC intercanine, IPM1 interfirst premolar, IPM2 intersecond premolar, IM1 interfirst molar

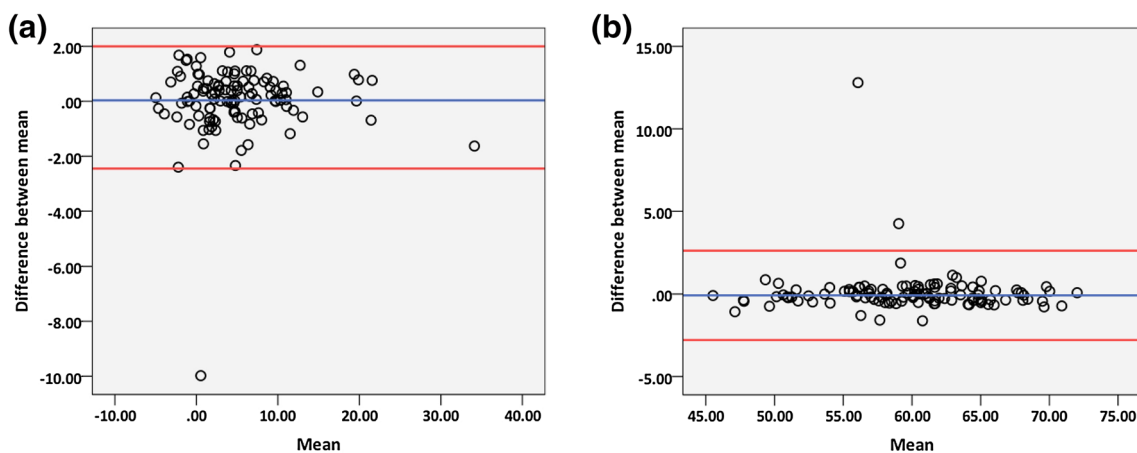
complex cases that need multidisciplinary collaboration. Furthermore, it is more cost effective and will improve the clinical and laboratory workflow.

Considering this, the present study investigated the potential of the blue light scanner in reducing some shortcomings of traditional analog methods (e.g., human error, material deformation, morphology location limitations). The innovative optical system enables it to differentiate object sizes, surface finishes, and shape complexities. Moreover, the blue light scanner has greater durability compared to laser and white light scanners. Data obtained from this study strongly suggest that the portable blue light scanner has a long-lasting light source

with a low temperature as it utilizes LEDs. In addition, it also has the ability to scan an object inside a well-lit room, while filtering out other light sources.

In determining the blue light scanner's dependability to be used in orthodontic practice, the device must be able to produce reliable and valid tooth arch parameter measurements of the 3D digital models. Despite some positive findings reported by other researchers on 3D digital models produced by other 3D extraoral laser scanner systems [3, 6, 11, 13, 24, 29], no study thus far has reported on the reliability and validity of the 3D digital models obtained from blue light extraoral scanner with LED technology. However, one similar study performed by Wiranto et al.





**Fig. 2** Bland–Altman analysis of mandibular **a** arch length and **b** space analysis  
**Abb. 2** Bland–Altman-Analyse von **a** Unterkieferbogenlänge und **b** Platzanalyse

[32] reported on the reliability and reproducibility of the digital models obtained from an intraoral scanner with an LED light technology (Lava Chairside Oral Scanner 3 M ESPE).

One important variable considered in this study is the repeatability of the measurements, where the same examiner must be able to reproduce the same measurements during the test–retest stage. In this study, ICC was measured on a scale of 0–1, where 1 represents perfect reliability with no measurement error and 0 indicates no reliability. At random, 20 models were selected and measured digitally and manually after a 2-week interval. As shown in Table 2, there was a significant positive correlation between the two measurements, thus, indicating excellent reliability. The single most striking observation emerged from the data was that the manual measurement of mesiodistal tooth width was excellent; however, it produces the lowest reliability (0.868–0.997) when compared to digital measurements. Furthermore, even though the plaster models were rescanned and remeasured digitally after a 2-week interval, results in Table 2 showed an excellent coefficient of reliability for both digital measurements. The positive correlation between digital and manual measurements suggests good digital measurement repeatability.

Of the 111 models, this study establishes that there were no significant differences ( $p > 0.05$ ) between the 3D digital model measurements of the arch width, arch length, and space analysis to those measurements obtained manually (Table 3). It was also not clinically significant as the difference is between 0.01 and 0.45 mm, which was less than 0.5 mm [5, 15]. Furthermore, significant, high, and positive correlations were found between digital and manual measurements ( $r > 0.970$ ). This result strongly indicates that the blue light scanner and software is reliable in reproducing and measuring the 3D model of the plaster

model. Nevertheless, a note of caution is due here since correlation is fairly a weak mechanism to use in determining the validity of an instrument. This condition therefore will require some discretion from other interested parties before further application on the usage of blue light scanner in clinical practice can be made. Manual tools in obtaining measurements may culminate from some inaccuracies due to handling errors and tool irregularities. Taken together, this could suggest that digital measurement may also produce the same inaccuracies due to the same problems.

Due to this, the Bland–Altman plot was used in assessing the variability of the data that demonstrate the reliability of the measurements collected in this study as shown in Table 4. The Bland–Altman plot is particularly useful in estimating the agreement between the two measurement methods of the same clinical variable that may be better than reliability coefficients. As shown in Table 4, the average mean differences were relatively small (0.00–0.13), indicating that the bias between the two measurements was small. In addition, the overall digital measurements on the study models (arch’s width, length, and space) showed good agreement (> 90%) compared to those collected manually. Surprisingly, the arch’s length and space analysis of the mandible demonstrated the highest agreement (99%; Table 4). Furthermore, the points on the Bland–Altman plot was 0 for arch length (Fig. 2a) and 0 for space analysis (Fig. 2b), suggests that there are no consistent bias between the two measurements of the arch.

The most important, relevant clinical findings of this study is that the results coincide with other studies that examined 3D measurements of digital models taken by laser scanning [3, 11, 13, 29] and CBCT [13]. Wiranto et al. [32] established that there was no significant difference between measurements obtained from the Lava

Chairside 3M ESPE intraoral scanner with LED light technology and those measured using a calliper on plaster models. This finding coincides with studies by Naidu and Freer [19] and Radeke et al. [23]. Thus, all these suggest a reliable and valid relationship between manual and 3D digital measurements. In addition, these findings suggest that the 3D blue light scanning technology has great potential and can be utilized in orthodontic practice.

In contrast to the foresaid findings, a study by Abizadeh et al. [2] established slightly higher mean differences of 1.15–0.17 between digital measurements of the arch's width and length obtained from R250 3Shape extraoral laser scanner to manual measurements. This is probably due to an error during the scanning process, which aimed at retaining as much detail as possible but ultimately removed important and necessary artifacts. In addition, errors may also occur during the merging process of the scanned images in order to produce a single composite image.

Previous studies have also reported differences in measurements between examiners [24] and maxillary space analysis [15]. A possible explanation of the differences might be due to difficulty in identifying precise and suitable measurement points, caused by the peculiar characteristics of a landmark that may be different from one another. As a result, it contributed to failure in producing and reproducing precise landmarks as a point of reference, despite performing calibration. Hence, actual measurement became inaccurate. Furthermore, the differences in the maxillary space analysis might be due to difficulty in assessing the maxillary arch length correctly as it is influenced by the maxillary anterior teeth inclination as opposed to the mandibular arch.

Other studies [4, 30, 33] also suggested that it can be challenging to identify suitable points, axes, and planes in creating a good 3D digital models, hence, causing differences in the mesiodistal tooth and arch width, and length measurements. In a way, these findings somewhat suggest that the operator's experience in handling the 3D digital models is also significant in obtaining accurate measurements. Moreover, the operator's familiarity with the software and the method in making measurements could also result in some inaccuracies [19].

As the literature presented in this study may suggest, there is a need to test the reliability and validity of 3D measurements using DS plaster models. Prior to this study, earlier work utilized pretreated plaster models of patients who had requested orthodontic treatment [6, 15, 24, 29]. As a result, these plaster models presented with only Class I, II and III malocclusions, had no missing teeth, and fully erupted permanent dentition from the M1 to the M1 on each arch. In addition, these plaster models could potentially present with less complex malocclusions if compared to the study models of DS subjects. Furthermore, the DS

study models require a different approaches altogether, due to the difficulty and challenges faced in obtaining correct measurements. Some considerations that need to be evaluated when measuring are the arch's width and length, presence of crowding, displacement of teeth, missing teeth, premature tooth loss, and impacted teeth [16]. All these suggest a good possibility of employing a blue light scanner as a tool in the orthodontic clinic as it resolves all the said complications.

One of the objectives of measuring the mesiodistal tooth width was to formulate treatment planning of the malocclusion. Mesiodistal tooth width provides crucial information on the amount of crowding, spacing, space analysis, and the Bolton discrepancies. A measurement of the arch width is also important because its value will significantly affect orthodontic treatment. First, it serves as a primary guideline for the clinician in maintaining it so that stability of the dentition can be assured following orthodontic treatment. Second, tooth arch parameter measurements also consist of intra-arch measurements which include the following: mesiodistal tooth width of the maxilla and mandible from the M1 to M1 on the either sides, arch's width, length, and space analysis. Although there are variations in the type of variables for measured tooth's arch parameter by examiners in other studies, the tooth arch parameter variable measured were comparable to other studies [3, 6, 7, 11, 13, 24, 27, 29, 33]. Furthermore, most studies measured the tooth arch parameter within the arch itself [6, 11, 13, 29]. Only a few studies measured the interarch relationships such as overjet, overbite, and midline discrepancy [6, 26, 30]. The maxillary and mandibular digital images need to be processed separately to become one model in the Geomagic software. The measurement of the interarch relationships is not a linear measurement on digital models and requires the examiner to plot the coordinate in the Geomagic software. Notably, performing these steps is far more complex.

The findings presented above strongly suggest the role of blue light scanner and software in promoting better clinical practice in orthodontic. Despite the findings, however, additional caution is deemed necessary to produce accurate measurement. First, calibration of the tools used must be performed prior to scanning of the models to ensure that the equipment works in the correct manner and able to produce high-quality 3D images. Second, the examiner must be properly trained to scan all plaster models and perform all measurements on both digital and plaster models. This step will ensure that the examiner is familiar in identifying the important measuring points when making digital models. Such an approach is important to determine the correct measurement of the arch width and length accurately when using the blue light scanner. Nevertheless, the number of examiners (two or

more examiners; interexaminer) should also be highlighted and evaluated in any future research centered on this type of scanner.

## Conclusion

The digital measurements of arch width, length, and space analysis of the 3D digital models of DS subjects obtained from blue light scanner are considered both reliable and valid. The measurement analysis on the digital models generated from the blue light 3D scanner is clinically acceptable for diagnosis and treatment planning and may be used to replace conventional plaster models analyses.

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## Compliance with ethical standards

**Conflict of interest** The authors declare that they have no competing interests. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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