A comparison between a new 2-dimensional digital on-screen tooth measurement method with direct measurements

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ABSTRACT

الأهداف: تقييم مدى دقة واستنساخ قياسات الأسنان باستخدام البرمجية التي تمّ تطويرها حديثاً والتي تعطي أبعاد ثنائية للصور الممسوحة ضوئياً لمجموعة الأسنان المنصوبة، ومقارنتها مع القياسات المباشرة باستخدام المسماك الرقمي.

الطريقة: أجريت هذه الدراسة في مختبرات الأسنان بكلية طب الأسنان، الجامعة الأردنية، عمان، الأردن وذلك خلال الفترة من سبتمبر إلى ديسمبر 2010م. لقد قمنا باستخدام 10 أطقم من الأسنان الأكريلية (10 قوس سني علوي، و10 قوس سني سفلي). وقد تم قياس العرض الأنسي–الوحشي لكل سن منفرد باستخدام المسماك الرقمي (الطريقة 1) والذي كان يُعد سابقاً معياراً ذهبياً. وتم صف الأسنان لتشكيل 20 مجموعة منصوبة حيث تم قياس الأعراض الأنسية–الوحشية باستخدام المسماك الرقمي (الطريقة 2). بعد ذلك تم مسح الأسنان المنصوبة باستخدام ماسح ضوئي رقمي مسطح، فيما تم قياس عرض الأسنان باستخدام برنامج كومبيوتر خاص لهذه العملية (الطريقة 3). وقد تم تقسيم القياسات السنية إلى 6 مجموعات، وعلى أساس ذلك قمنا بعمل مقارنة بين الطرق الثلاث.

النتائج: لقد كان هناك فروقاً واضحة بين طرق القياس الثلاثة في الغالبية العظمى من مجموعات الأسنان المُقاسة. وأشارت نتائج الدراسة إلى ظهور فروق واضحة بين الطريقتين الأولى والثانية وذلك بالنسبة لغالبية مجموعات الأسنان (تراوحت ما بين 0.02 إلى 0.22 مم)، بينما لم تكن هنالك فروق كبيرة بين الطريقتين الأولى والثالثة (تراوحت ما بين 0.03 إلى 0.11 مم).

خاتمة: أظهرت الدراسة مدى التشابه بين نتائج قياس عرض الأسنان على الشاشة باستخدام الصور ثنائية الأبعاد لمجموعات الأسنان الممسوحة ضوئياً ونتائج القياسات التي تم الحصول عليها مباشرة باستخدام المسماك الرقمي.

Objectives: To compare the accuracy and reproducibility of tooth measurements using newly developed software that gives 2-dimensional scanned images of dental setups with direct measurements using digital calipers.

Methods: This experimental study was performed at the Dental Laboratories of the Faculty of Dentistry, University of Jordan, Amman, Jordan from September 2010 to December 2010. Ten sets of acrylic teeth (10 upper and 10 lower arches) were used. The mesiodistal width of each individual tooth was measured using a digital caliper (method I), which was considered the gold standard. The teeth were set to create 20 dental setups. The mesiodistal widths of teeth on the created setups were then measured by using a digital caliper (method II). The dental setups were then scanned using a flatbed computer scanner and tooth width measurements were performed using a special computer program (method III). Tooth measurements were divided into 6 groups, and the 3 methods were compared.

Results: There was a statistical significant difference between the 3 measurement methods in most of the measured tooth groups. Methods I and II exhibited significant differences for most of tooth groups (ranged from 0.02 to 0.22 mm) while no significant difference was found between methods I and III (ranged from 0.03 to 0.11 mm).

Conclusions: Tooth width measurement with on-screen 2-dimensional scanned images of dental casts is comparable to measurements obtained using direct digital caliper.

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Study models in addition to radiographs, photographs and clinical examination provide information needed for orthodontic diagnosis and treatment planning. They provide a 3-dimensional view of a patient's occlusion and facilitate routine measurements as compared to intraoral measurements.[1] Arch measurements on study models are routine and essential steps in orthodontic analysis of a patient's occlusion and are frequently used by general dentists, pediatric dentists as well as orthodontists. Direct orthodontic measurements using calipers or pointed dividers have been a widely used method in the dental clinic,[2] but have the drawback of being difficult to apply in crowded dentitions.[3] The alternative is the new 3-dimensional computerized dental models[4,5] which involves the patients' study models being sent to one of the companies for processing into a virtual 3-dimensional computerized image that is then available for the dentist to download from the company website. This method has many advantages in terms of electronic patient recording and storage as well as accuracy compared to traditional caliper measures.[6-9] However, the increased cost, delayed result, and inaccessibility to these companies internationally make it a poor choice for simple mixed dentition analysis and uncomplicated orthodontic cases frequently seen by general and pediatric dentists.

Digital photographs of study models have been used for space analysis measurements and were found to be reliable and clinically acceptable compared to direct measurements with calipers and Digimodel software in a recent study.[10] Digital images are composed of very small dots, referred to as pixels, arranged in rows and columns. These images have a variable scale ratio; in other words, the number of pixels represented at one part of the image may differ from those at another area. On the other hand, images generated by a flatbed scanner have a fixed overall scale ratio with the number of pixels being the same across the image. This is referred to as the scanning resolution of the image. Such a resolution is usually measured in a unit called dpi (dots per inch) or ppi (pixels per inch). This means that if an object was scanned at a resolution of 300 dpi, this means that every inch on the computer image of the scanned object would be represented by 300 pixels. As a result, dental measurements can be more easily calculated from a scanned image compared to a digital photograph with the resulting scanned image producing images having a scale ratio of 1:1 to the size of the scanned object when the object is sitting directly on the scanning glass. The development of software to measure the distance between 2 points on an image by simply counting the number of pixels between these 2 points on the computer image and dividing them by the scanning resolution allows simple measurements to be carried out.

A Medline search up to January 2011 revealed no studies investigating the potential for space analysis using 2-dimensional images of scanned dental casts. The aim of this study is to compare the accuracy and reproducibility of tooth measurements using newly developed software that gives 2-dimensional scanned images of dental setups with direct measurements using digital calipers.

Methods.

Measurements. This study was performed at the Dental Laboratories of the Faculty of Dentistry, University of Jordan, Amman, Jordan between September 2010 to December 2010. Ten sets of acrylic teeth (240 teeth, 10 upper, and 10 lower arches) were used in this study. The mesiodistal width of each individual tooth was measured by a single examiner using a digital caliper (Orteam, Lotto 56, Milano, Italy) with an accuracy of 0.01 mm. The measurements were performed by holding the tooth vertically and placing the blades of the caliper on its contact points with the blade's proximal sides parallel to the long axis of the tooth (method I). This method was considered to be the "gold standard" with which the measurements of other methods were compared. The teeth were then set by a dentist on dental casts of edentulous arches using thermoplastic silicone to create 20 dental setups. The setups simulated the variable classes of malocclusion with different degrees of tooth displacements, inclinations, angulations, rotations and variable depths of the curve of Spee (**Figure 1**). The mesiodistal widths of the teeth were then measured for all teeth (incisors, canines, premolars and first molars) using 2 measurement methods. The mesiodistal width of each individual tooth was measured on the created setups by the same examiner using the same digital

Figure 1 - Setting of individual teeth to simulate dental arrangements within the arches.

caliper described in method I. The measurements were taken by placing the blades of the caliper in the facial embrasures horizontally at the level of contact areas of the teeth (method II).

The dental setups were then scanned using a computer scanner (HP, model 4150, CA, USA). The scanning was performed by placing the occlusal surfaces of the dental setups on the scanner in a position that allows the maximum number of teeth to contact the scanner's surface. The scanning resolution was 300x300 pixels per square inch. The resulting images were then imported into a computer program (Macromedia Flash MX 2004 [Macromedia Inc., San Francisco, CA, USA]) that was specially developed for this study by one of the author (Saleh MW). This computer program was designed to measure the distance between any 2 given points on a dental cast by counting the pixels between the 2 points on the scanned image of the dental cast and calculating the distance in millimeters taking into consideration the resolution employed in scanning. The program shows the scanned image of the model and an on-screen caliper which can be positioned using the standard computer mouse cursor. The caliper is rotated to follow the line of the arch and then the operator adjusted the distance between the 2 blades until they create tangents to the contact areas of the measured tooth (**Figure 2**). Tooth measurements were recorded for each setup and saved as a single dataset on a separate Microsoft Excel 2003 sheet (Microsoft Corporation, Redmond, WA, USA) (method III).

Error of the method. The error of the method was tested to ensure intra-examiner reliability by repeating the same measurements at different times. The measurements were retaken for 80 teeth in the setups by the same examiner for each measurement method with a 2-week interval between the measurements. Intra-examiner errors of measurements were assessed for each method as recommended by Dahlberg[11] and Houston.[12]

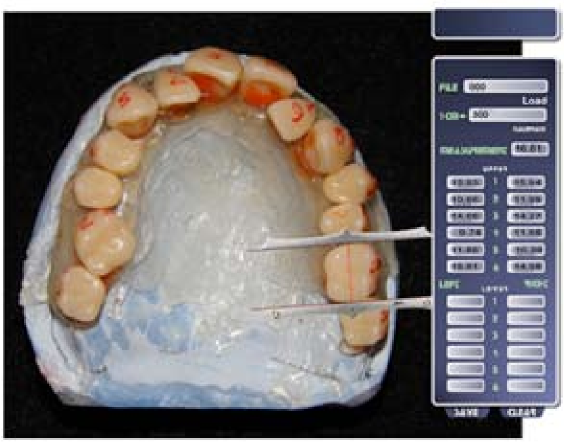

Figure 2 - On-screen measurement of mesiodistal tooth width (method III).

The mean errors calculated by Dahlberg's formula ranged from 0.02 to 0.08 mm for method I, 0.06 to 0.22 mm for method II, and 0.09 to 0.28 mm for method III (**Table 1**).

Systematic errors were assessed by paired t-tests to compare repeated measurements of teeth using the 3 measurement methods as recommended by Houston.[12] No significant differences were found between the repeated measurements in any of the methods (**Table 2**). These values indicate that the measurement errors were not clinically significant and unlikely to bias the results of this study.

Statistical analyses. Tooth measurements were divided into 6 groups (group I: upper incisors and canines; group II: upper premolars; group III: upper first molars; group IV: lower incisors and canines; group V: lower premolars; and group VI: lower first molars). Shapiro-Wilk normality test was carried out to confirm the normality of distribution in each group. The test showed that only one of the groups (Group IV) was not normally distributed, but the sample size of that group was large enough to assume the normality of distribution in accordance with the central limit theorem. Repeated measures ANOVA with post hoc pairwise comparisons implementing Bonferroni's correction were undertaken

Table 1 - Random errors for the mesiodistal tooth widths in millimeters calculated by Dahlberg's formula.

Teeth Group	Number	Random Errors (mm)		
		Method I	Method II	Method III
Maxillary				
Group I: Incisors and canines	12	0.06	0.18	0.13
Group II: Premolars	8	0.08	0.19	0.11
Group III: Molars	4	0.07	0.22	0.09
Mandibular				
Group IV: Incisors and canines	12	0.02	0.06	0.21
Group V: Premolars	8	0.06	0.08	0.28
Group VI: Molars	4	0.04	0.10	0.18

Table 2 - Results of paired t-tests carried out to assess systematic errors of measurements for the 3 measurement methods.

Methods	SE	SD	Mean Difference	P-value
Method I	0.008	0.057	-0.006	0.470
Method II	0.030	0.208	0.008	0.798
Method III	0.037	0.257	-0.065	0.084

SE, standard error, SD, standard deviation to determine whether a statistically significant difference existed between the 3 measurement methods for all tooth groups. All data sets were rigorously treated at the 95% level of confidence. Ninety-five percent level of confidence was selected for all statistical tests performed.

Mauchly's test of sphericity was performed to ensure the accuracy of the results of the repeated measures ANOVA test.

Results. Measurements for all tooth groups were recorded for each method and described in terms of average values, standard deviations, and variances (**Table 3**). The difference between the means of tooth width using method I (gold standard) and method II ranged from 0.02 to 0.22 mm and between method I and method III ranged from 0.03 to 0.11 mm (**Table 4**). The results showed that method II underestimated the measurements when compared to the gold standard (method I). On the other hand, method III alternatively showed higher and lower mean values compared to the gold standard (**Table 4**). Repeated measures ANOVA showed a statistically significant difference between the 3 measurement methods in all tooth groups except group V (Table 4). Mauchly's test of sphericity indicated that the assumption of sphericity had been violated in groups I, IV, and V. Therefore, the degrees of freedom were corrected using Huynh-Feldt estimates of sphericity for group I (epsilon = 0.81) and Greenhouse-Geisser estimates of sphericity for groups IV and V (epsilon = 0.74). Pairwise comparisons have shown that methods I and II exhibited significant differences for all tooth groups except groups III and IV while no significant

Table 3 - Means, standard deviations and variances for all tooth groups and measurement methods (in millimeters).

Teeth Group	N	Method I			Method II			Method III		
		Mean ± SD		Variance	Mean ± SD		Variance	Mean ± SD		Variance
Maxillary										
Group I: Incisors and canines	60	7.38	0.84	0.70	7.32	0.84	0.71	7.34	0.84	0.70
Group II: Premolars	40	6.37	0.31	0.10	6.26	0.31	0.10	6.40	0.32	0.10
Group III: Molars	20	9.32	0.53	0.28	9.22	0.48	0.23	9.38	0.52	0.27
Mandibular										
Group IV: Incisors and canines	60	5.54	0.55	0.31	5.52	0.55	0.31	5.63	0.53	0.28
Group V: Premolars	40	6.50	0.47	0.22	6.39	0.47	0.22	6.42	0.49	0.24
Group VI: Molars	20	9.82	0.68	0.46	9.60	0.69	0.48	9.71	0.65	0.42

Table 4 - Repeated measures Analysis of Variance of the 3 measurement methods for the 6 tooth groups

Teeth group	*N*	Measurement methods	Mean (mm)	Mean difference with Method I (mm)	*P* value with Method I (Bonferroni's correction)
Maxillary					
		Method II	7.32	-0.06‡	0.001
Group I: Incisors and canines	60	Method I (gold standard)	7.38		1.000
		Method III	7.34	-0.04	0.363
		Method II	6.26	-0.11‡	0.023
Group II: Premolars	40	Method I (gold standard)	6.37		1.000
		Method III	6.40	0.03	1.000
		Method II	9.22	-0.10	0.080
Group III: Molars	20	Method I (gold standard)	9.32		1.000
		Method III	9.38	0.06	0.467
Mandibular					
		Method II	5.54	0.02	0.527
Group IV: Incisors and canines	60	Method I (gold standard)	5.52		1.000
		Method III	5.63	0.09‡	0.010
		Method II	6.39	-0.11‡	0.001
Group V: Premolars	40	Method I (gold standard)	6.50		1.000
		Method III	6.42	-0.08	0.323
		Method II	9.60	-0.22‡	0.001
Group VI: Molars	20	Method I (gold standard)	9.82		1.000
		Method III	9.71	-0.11	0.135

‡Significant differences were detected between measurements at $p<0.05$

difference was found between methods I and III except for group IV (**Table 4**).

Discussion. This is the first study in the literature looking at the accuracy of tooth measurements from scanned 2-dimensional images of dental setups compared to a gold standard of direct measurements with a digital caliper. The advantages of this concept are that the tools needed are commonly available in most dental offices (a personal computer with a standard scanner) in addition to the ease of data recording and analysis. Paredes et al[13] in 2005 introduced a method of performed tooth measurements by scanning stone dental casts and producing a 2-dimensional image of the cast on the computer for calculation of Anterior Bolton Index and Overall Bolton Index. However, their method required a calibration step every time dental measurements were performed which had the possibility of introducing errors that could affect the measurements taken. The computer program developed for this investigation imports the scanned images of dental models at any resolution and has the capability to compensate for the resolution magnification to ensure recording actual measurements without the need for a calibration step before each measurement. This feature enables the examiner to visualize a larger version of the dental model with clear details and more visible landmarks.

The dental setups used in this study were considered substitutes for the plaster models of dental arches. Impressions of the setups were not taken to create dental casts so as to avoid introducing another variable related to the dimensional stability of the impression material that could affect the results.[14,15] The scanning and method of measurement applied in the present study can similarly be applied on plaster dental models. Previous research work looking at the accuracy of measuring teeth on models produced from different impression materials have found conflicting results.[16,17]

Using a caliper to measure crowded teeth is difficult because of the inaccessibility of contact areas to the blades of the caliper, which forces the examiner to move the caliper in different directions and planes to record the measurements compromising the reproducibility and accuracy of the measurements. Shellhart et al[3] found that clinically significant errors in measurements (>1.5 mm) occurred when the direct measurement method was used when the crowding exceeded 3 mm. Although method I cannot be applied clinically, it enables the examiner to accurately measure the mesiodistal dimensions of the teeth by visualizing their proximal heights of contour without the hindering from the contact areas as in dental arches. Therefore, this method was considered to be the "gold standard" with which the measurements of other methods were compared.[7] Interestingly, random errors were higher in the maxillary than the mandibular tooth groups when method II was used, while they were higher in mandibular than maxillary tooth groups when method III was used (**Table 1**). There are no similar studies in the literature which could explain this finding. The difference in the random errors between the maxillary and mandibular arches may be attributed to the difference in the morphology and size of the teeth. However, this needs to be confirmed by further investigations.

Statistical tests comparing the 3 measurement methods showed that method III was closer to the gold standard (method I) than method II. Statistically significant differences were found in 4 of the 6 tooth groups for method II (**Table 4**). The mean differences of tooth measurements using method II, however, did not exceed 0.22 mm for any of the tooth groups, and these differences were always an underestimation of the actual tooth size. This might possibly result in an underestimation of the space required to alleviate the crowding when space analysis is carried out, but since the mean differences were equal to or less than 0.22 mm in all tooth groups then these differences are probably of little if any clinical significance.

The results of this study show that the measurements taken by method III showed a statistically significant difference from the gold standard in only one of the tooth groups, the mandibular incisors, and canines (**Table 4**). There were no similar studies in the literature which could explain this finding. A possible explanation is that the mandibular incisors have proximal surfaces that are almost parallel as opposed to other teeth and so locating the contact areas from a 2-dimensional image where no tactile sensation is available is more difficult. However, although this difference was statistically significant, it is clinically not significant with the mean difference being less than 0.1 mm (**Table 4**). The mean differences were equal to or less than 0.11 mm for all tooth groups and did not show any trend of over- or under-estimation of the actual tooth size. Compared to method II, on-screen measurements (method III), has the advantage of being able to enlarge the occlusal images on the screen enabling better visualization of tooth surfaces.

The results of this investigation suggest that tooth width measurement using scanned 2-dimensional computer images of dental casts is comparable to direct measurements using digital calipers. Moreover, it is easier than direct measurements and facilitates the data entry and storage into computerized patient's records. There are, however, limitations of this study in investigating the applicability of this method for all types of malocclusions and dental anomalies. Although many dental setups were used for this study and these comprised a wide range of tooth positions, the effects of the specific tooth morphology or position in the 3-dimensional space such as its inclination or angulation and the effects of variations of arch shapes and curvatures in 3-dimensional planes on the accuracy of this method were not thoroughly investigated in this study and should be investigated in future studies.

The software program developed has the advantages of the newly developed 3D technology, but with decreased cost and better accessibility. It would be especially useful for general dental practitioners and pediatric dentists who treat simple orthodontic cases in their practices.[18,19] The program may also be used by trained orthodontic or dental auxillaries to allow space analysis to be carried simply and accurately with a minimum of clinical time. In addition, there may be a role for this software in education and training of dental students in the techniques of space analysis.

Further, development of the software will be for it to be used as a utility to perform mixed dentition and Bolton analyses for different populations based on the norms published in the literature. The software may also have other non-orthodontic uses as seen in previous research using similar software.[20]

There is a need for further investigation on the effect of the different types of impression materials and their dimensional stability in a clinical situation when using the method described in this study.

In conclusion, it was found in this study that tooth width measurements with on-screen 2-dimensional scanned images of dental casts in the study was comparable to the direct digital caliper measurements.

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