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A new system for scanning, measuring and analyzing dental casts based on a 3D holographic sensor

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Structured Abstract

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Objectives – To evaluate the reliability of a new technique for measuring 3D-scanned orthodontic cast models with cross-section planes using TELEDENT, a new software, developed at Technion – for the purpose of this research.

Experimental Variable – Thirty orthodontic plaster models were divided into three equal groups according to severity of teeth crowding. Measurements of mesio-distal tooth width and the arch length were performed manually on the casts using a conventional caliper. Thereafter, the models were scanned and processed into the software using a 3-D measuring scanner with a holographic sensor 'ConoProbe' (by Optimet®, Jerusalem, Israel). TELEDENT used two types of digital measurements; linear and cross-section planes to perform a space analysis on the scanned teeth. Significance was determined by the paired Wilcoxon rank sum test.

Results – Results show that 3D measurements of tooth width and arch length obtained by cross-section planes were generally similar to manual caliper measurements, while linear measurements were statistically smaller. When comparing space analysis, both digital measurements were statistically smaller than the caliper ($p < 0.05$). The difference in space analysis between the caliper and the cross-section plane measurements was very small (0.38–0.74 mm) and can be considered clinically acceptable. However, a difference of 1.19–3 mm between the linear measurements and the caliper might have clinical implications especially in severely crowded dentition.

Conclusions – This study suggests that measurements performed by cross-section planes are as accurate as the manual caliper and can be employed clinically while the accuracy of linear measurements is sometimes questionable.

Key words: computer simulation; dental models; odontometry; reproducibility

Introduction

To obtain an accurate orthodontic diagnosis, orthodontists use various types of measurements and analysis. Common measurements performed on plaster casts include tooth width and arch length, both needed for space analysis (1). These measurements provide space assessment which is often necessary to determine the appropriate treatment plan. Currently,

this procedure involves time (laboratory), space (storage) and retrieval for clinical use. Traditionally, these measurements have been manually made on plaster models using a caliper. The digital caliper is considered to be accurate, reliable and reproducible (2–5).

Today's 3D sensor technology provides new potential alternatives to replace the manual measurements which include 3D digital images of scanned objects followed by computerized measuring software. Utilization of this technology in orthodontics has several advantages including accurate measurements, storage and time saving as well as online consultation and presentation possibilities (6–9). Currently, a few companies provide clinically operational digital software (10, 11) which enables the users to perform different measurements and calculate data from the digital model. *TELEDENT* which was developed at Technion for the purpose of this research (12) offers a new means of space analysis, mainly the cross-section planes. After scanning the orthodontic cast model with the holographic sensor ConoProbe (Optimet, Jerusalem, Israel), the data is imported to *TELEDENT* for computerized space analysis. The *TELEDENT* software provides interactive graphical tools such as cross-section planes which are used to mimic the digital caliper arms. This tool allows the user to place a pair of cross-section planes in any desired position and orientation, while displaying the cross-section of the mold on each plane, thus achieving the widest mesio-distal measurement of the tooth. The purpose of this study was to assess the accuracy of this new technique compared with the gold standard of the digital caliper (4) and to the digital linear measurements which are available today.

Materials and methods

Thirty pairs of orthodontic cast models of mixed and permanent dentition obtained from the Department of Orthodontics, Hadassah Faculty of Dental Medicine were divided into three equal groups according to the severity of teeth crowding: A, no crowding (with or without spacing); B, mild (1–3 mm crowding per arch); C, moderate to severe (>4 mm per arch). The partition into the three crowding groups was carried out clinically by a specialized orthodontist in

the Department of Orthodontics; the clinical observation was confirmed with space analysis calculation for each study model as follows: mesio-distal width measurements of incisors, canines, premolar, first molar teeth and the arch length (between first molars) were performed on the plaster casts and on the digital scanned models. Cast measurements were performed with a digital caliper with a precision scale of 0.01 mm (Capaµ System®; TESA Technology, Renens, Switzerland).

The cast models were scanned using Optimet's scanner with the ConoProbe holographic sensor (Fig. 1). This scanning system provides precision up to 15 µm and enables measurements of complex geometric objects as well as angles up to 85° which facilitates measurement of undercuts as found in orthodontic cast models.

The scanned data were processed and viewed with the 3D *TELEDENT* software developed especially for this research purpose by the Lab of computer graphics and CAD, Faculty of Mechanical Engineering, Technion, Haifa, Israel (12). Digital computerized measurements of the mesio-distal tooth width of permanent dentition were performed as follows:



Fig. 1. Optimet 3D scanner with the 'ConoProbe' Holographic sensor.

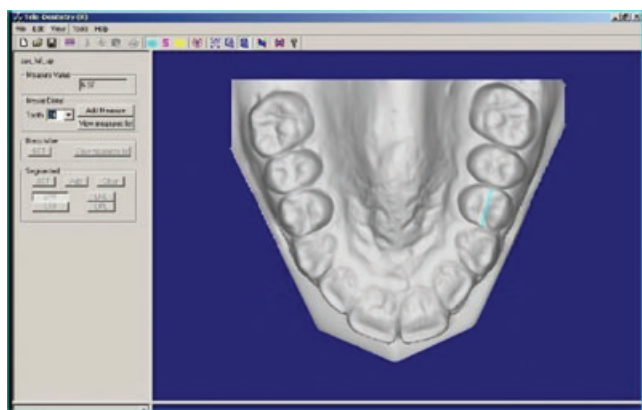


Fig. 2. TELEDENT tooth width measurement with linear measurements.

1. The linear measurements: drawing a transverse line from the occlusal view on posterior teeth and from the facial view on anterior teeth in the mesio-distal's widest dimension (3–5, 9) (Fig. 2).
2. The cross-section plane measurements: using two fixed parallel cross-section planes with a cross-section window which provides a more accurate determination of the widest tooth dimension (Fig. 3).

The space analysis calculation was determined by using each tooth width as required. Segmental arch length was measured using non-fixed cross-section planes as detailed herein: each jaw was divided into four segments (13) as follows: right and left anterior from the mesial of the canine to the midline; right and left posterior from the mesial of first molar to the mesial of the canine. The points of separation between

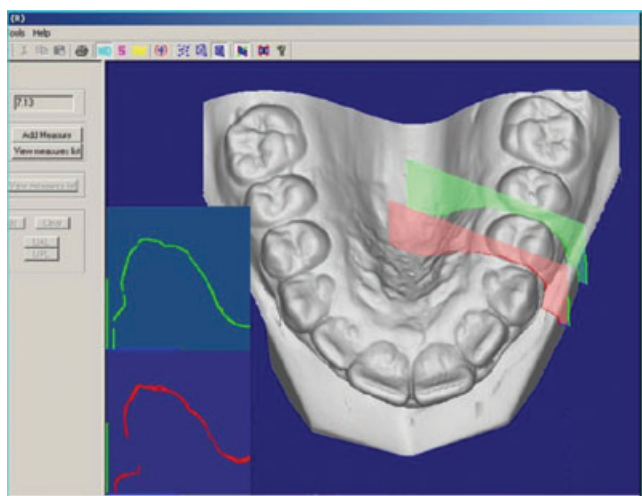


Fig. 3. TELEDENT tooth width measurement with cross-section planes.

the segments were chosen using the cross-section planes similarly to the mesio-distal tooth measurement with a cross-section of the model presented on screen and a point chosen on the curve of the tooth.

It should be emphasized that the cross-section feature currently allows measuring the teeth width only. Nevertheless, it has versatility in the 3D analysis. Moreover, it has the potential for measuring mesio-distal width, mesio-distal angulation and rotation as well as determining contact point / area between two adjacent teeth. All measurements were performed three times by the same investigator (T. W.).

Models which had undercuts sharper than 85° were scanned twice from 90° and 45° to the surface and a computerized registration matrix was used to integrate both range images into a complete detailed 3D model within the TELEDENT software. The registration process can cause additional errors therefore a special module was developed (Technion) to minimize scanned model errors.

For the calculation of space analysis, the value of the homological tooth was entered when a permanent tooth was missing. If both teeth were absent, the higher of the following values was entered:

1. Standard teeth size values from Concise Dental Anatomy and Morphology by Fuller JL, Denehy GE, Chicago, USA; 1977 (14).
2. Teeth width values taken from the University of Minnesota (15).
3. An average of teeth sizes obtained from the values calculated in this study group consisting of 30 models.

Following the arch measurements, space analysis was calculated.

Statistical analysis

Means and SEs were calculated for continuous ranges of variables. As the sample groups were small in size (ten patients in each group) non-parametric statistical tests were used. The results of the three groups (A / B / C) were analyzed and compared using the 'Kruskal-Wallis comparison test' to test the null hypothesis that several samples are from the same population. The results of the pairs of subgroups were analyzed and compared using the 'Wilcoxon rank test' (16).

Results

Measurements of tooth width and segmental arch length obtained by cross-section planes were generally similar to the manual caliper cast measurements with the exception of group C mandible which was statistically smaller in the cross-section planes measurements ($p < 0.05$). However, such a small difference (0.04–0.5 mm) per arch has no clinical implications (Tables 1 and 2). Linear digital measurements of tooth width and segmental arch length were statistically smaller ($p < 0.05$) in groups B and C than the caliper

Table 1. Mean tooth width size measured in each jaw (mm)

Groups	Maxilla			Mandible		
	Mean	SE	Range	Mean	SE	Range
Group A						
Caliper	7.52	0.16	6.44–8.38	7.00	0.11	6.97–8.21
Digital line	7.53	0.08	7.13–8.05	6.96	0.10	6.74–7.18
Virtual planes	7.65	0.10	7.34–8.34	7.07	0.11	6.56–7.62
Group B						
Caliper	7.76	0.11	6.97–8.21	7.06	0.10	6.55–7.44
Digital line	7.48*	0.10	6.94–8.07	6.94	0.08	6.47–7.21
Virtual planes	7.74	0.11	7.00–8.20	7.04	0.10	6.53–7.40
Group C						
Caliper	7.82	0.10	7.37–8.29	7.25	0.08	6.87–7.67
Digital line	7.64*	0.10	7.27–8.08	6.97*	0.09	6.56–7.43
Virtual planes	7.80	0.10	7.37–8.27	7.21*	0.08	6.85–7.62

*Significant at $p < 0.05$.

Table 2. Arch length measurements (mm)

Groups	Maxilla			Mandible		
	Mean	SE	Range	Mean	SE	Range
Group A						
Caliper	74.73	1.80	62.71–81.53	65.82	1.32	58.58–73.28
Digital	74.89	1.72	63.56–81.98	66.85	1.27	58.38–73.70
Group B						
Caliper	73.63	0.80	68.53–76.9	64.79	1.48	55.23–71.36
Digital	73.78	0.88	68.55–77.5	65.37	1.35	55.9–71.33
Group C						
Caliper	72.0	2.18	60.2–82.82	61.92	1.07	54.97–68.0
Digital	72.25	2.09	60.8–82.38	62.42*	1.04	55.14–67.63

*Significant at $p < 0.05$.

Table 3. Space analysis

Groups	Maxilla			Mandible		
	Mean	SE	Range	Mean	SE	Range
Group A						
Caliper	4.81	0.75	1.17–8.06	3.53	0.67	0.85–7.00
Digital line	6.00	0.88	0.4–9.05	4.06	1.65	–1.98–9.02
Virtual planes	4.95	0.71	1.53–7.38	3.38	0.90	–1.06–7.91
Group B						
Caliper	1.64	0.40	–0.33–3.53	0.96	1.14	–4.30–7.27
Digital line	4.02*	0.52	1.08–6.26	2.77*	0.87	–1.34–6.00
Virtual planes	2.02*	0.39	–0.19–3.52	1.70*	0.93	–1.66–7.04
Group C						
Caliper	–2.21	1.58	–9.76–4.68	–3.60	0.96	–9.88–2.10
Digital line	–0.12*	1.64	–9.28–6.50	–0.55*	0.88	–6.29–3.37
Virtual planes	–1.66*	1.58	–9.34–5.48	–2.94*	0.92	–9.56–1.62

*Significant at $p < 0.05$.

measurements (Tables 1 and 2). However, this small difference (0.18–0.28 mm) lacks clinical relevance.

Comparison of space analysis calculated from the cross-section planes measurement with that obtained by manual caliper showed a significant difference in the mild to moderate-severe crowded dentition (groups B, C); however, again such a small difference (0.38–0.74 mm) can be considered clinically acceptable (Table 3).

Comparing space analysis between computerized linear measurements and manual caliper measurements showed significantly less crowding when using the linear measurements ($p = 0.02$) in groups B and C (1.19–3 mm). Such a difference (3 mm per arch) may be of clinical importance.

Discussion

The results of this study show that using cross-section planes for measuring tooth width and arch length does not differ from using the caliper on plaster models and can therefore be employed for clinical purposes. The advantages of using a computerized measuring system as mentioned earlier, include accurate and detailed measurements, savings in time and storage space (6–8) as well as online consultation and presentation possibilities (4, 5, 9). The cross-section planes enable the

user to more accurately estimate the contact points between the measured teeth, and therefore contribute to the accuracy of the results.

The statistical discrepancy found in group C mandible can be attributed to the difficulty of measuring teeth in the crowded dentition, and raises the question of whether manual measurement is indeed more accurate than digital measurement with a cross-section that offers an easier view.

The linear measurements were found to be statistically smaller but clinically acceptable, in the non- to mild-crowded dentition, similar to the results obtained by Zilberman et al. (5) who evaluated the OrthoCAD system. A possible explanation for this could be the 2-D line measurement deformation (17), and the difficulty in placing the line in the correct points of measurement (4, 5, 7).

OrthoCAD by Cadent (Carlstadt, NJ, USA) (10) is a commercially available digital technology which enables transformation of dental impressions or plaster casts into 3D virtual models. Recently, OrthoCAD added a new technique using transverse planes to the former mesio-distal measurements using linear measurements very similar to the cross-section planes presented in this study. This paper did not study the OrthoCAD system and therefore, we do not presume to compare the two measuring systems or to evaluate OrthoCAD's accuracy. Nonetheless, the recent development of cross-section plane measurements employed in OrthoCAD software might suggest that using cross-section planes could be more accurate or more technically convenient for the user than the former linear measuring method.

Arch length measurements showed similar results, and support the cross-section planes as a reliable means of measurement. However, when using both parameters to calculate space analysis, despite the good correlation between cross-section planes and caliper, both cross-section planes and linear measurements show statistically larger results, which indicate a less-crowded dentition than the manual results. An explanation for this discrepancy could be mathematical because of summation and calculation of the tooth width and the arch's segmental length, which may have caused the difference in the results. When clinically considering the results of space analysis, the discrepancy between manual caliper and cross-section planes measurement is acceptable (0.38–0.74 mm) and is unlikely to alter the treatment plan.

However, as the discrepancy between the linear and caliper measurements is large (1.19–3 mm), it may cause severe crowding to look like moderate crowding and consequently influence the treatment plan. This finding, questions the accuracy of current clinical softwares which still use the computerized linear measurements when calculating space analysis.

Conclusion

1. The accuracy of the technique of cross-section planes measurement of 3D-scanned cast models does not differ from manual caliper measurement of casts.
2. Cross-section plane measurements are more accurate than linear measurements.
3. Linear measurements may cause clinical inaccuracy when calculating space analysis in a crowded dentition.

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