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The evidence supporting methods of tooth width measurement: Part II. Digital models and intra-oral scanners

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Digital models and intra-oral scanners are gaining increasing popularity in orthodontic diagnosis and treatment planning by allowing clinicians to store and 'virtually' analyse dental casts. The present paper reviews the various digital model programs and available intra-oral scanners and presents the research which has tested their accuracy. With this information, clinicians may be better informed to adopt the most appropriate system.
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Introduction

Recently, digital models and intra-oral scanners have been introduced to the discipline of orthodontics. Both offer advantages which can significantly improve practice efficiency. The aim of this paper is to explore the evidence supporting the use of digital models and intra-oral scanners for performing tooth-size analyses. In addition, the advantages and disadvantages of each system will be discussed.

3D digital models

Digital study models were first introduced in 1999 by OrthoCAD (Cadent, Carlstadt, NJ, USA) (Figure 1), and were followed in early 2001 by the emodel system (GeoDigm, Chanhassen, MN, USA).[1,2] More recently, DigiModel (Orthoproof, Nieuwegein, The Netherlands) (Figure 2) and Lava Digital Models (3M Unitek, Monrovia, CA, USA) have been released.[3-5] Generally, alginate impressions of the patient's dentition and a wax registration bite are required in order to generate the models.[2,4,6,7] OrthoCAD and the emodel system require the impressions to be poured in plaster to produce study casts which are subsequently scanned to create a virtual model.[2,8] DigiModel and Lava Digital Models perform direct scanning of the alginate impression.[4,5] Flash computerised tomography (CT) is used to record the impression details which removes the need for plaster casts.[4,5] Once the digital models have been generated, they are made available to the practitioner for downloading from the company's web site[2,7,8] or data files may be electronically sent to the office.[3,6] The clinician is able to view the 3D models on provided software and conduct routine measurements such as tooth widths, overjet, overbite, arch length, arch width, and perform a Bolton analysis.[7]

Numerous studies, particularly using the OrthoCAD system, have evaluated the use and value of 3D digital models in the analysis of tooth size.[1] In 2001, Tomassetti et al. assessed four methods of calculating overall and anterior Bolton ratios using 22 sets of models.[9] The mean Vernier caliper values were compared to values derived from 3 computerised methods including QuickCeph (QuickCeph Systems, CA, USA), the Hamilton Arch Tooth System (HATS) (GAC International, NY, USA) and OrthoCAD.[9] No statistically significant differences in Bolton ratios existed between the methods ($p < 0.05$).[9] However, clinically significant differences

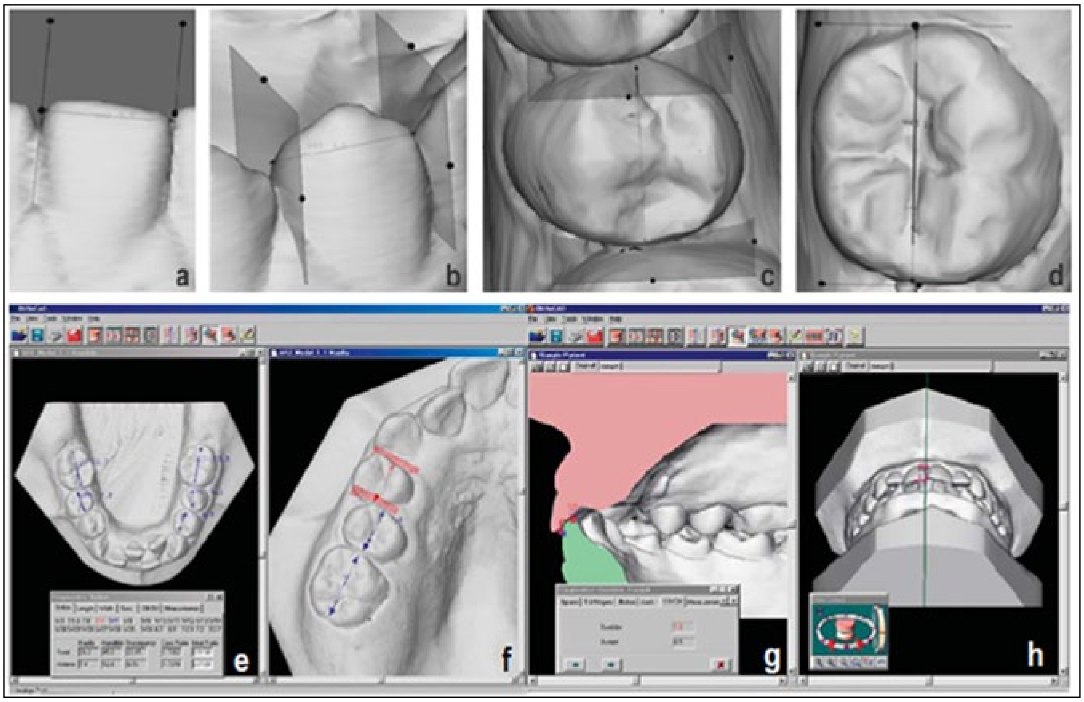

Figure 1. Measurement of an (a) incisor, (b) canine, (c) premolar, and (d) molar using the OrthoCAD measurement tool; (e and f) more tooth size measurements; and (g) overjet and overbite measurements after (f) selecting an appropriate plane of section.[7,10]

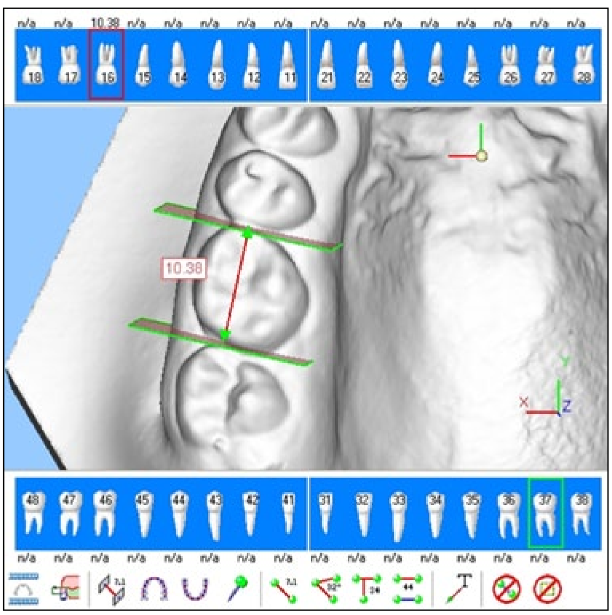

Figure 2. Measuring the first permanent molar with DigiModel.[3]

(> 1.5 mm) were evident for all methods.[9] QuickCeph was the fastest in performing the analyses (1.85 minutes) followed by HATS (3.40 minutes), OrthoCAD (5.37 minutes), and Vernier calipers (8.06 minutes).[9] The authors concluded that time-efficient computerised methods are available to perform Bolton analyses but accuracy might be compromised.[9]

Zilberman et al. in 2003, assessed the accuracy of measuring casts with OrthoCAD compared with caliper measurements.[10] The software measurements were highly correlated (R = 0.763 – 0.975) with no statistically significant differences.[10] In addition, inter- and intra-observer errors were small.[10] The OrthoCAD measurement tool therefore showed high accuracy and reproducibility which was considered to be clinically acceptable.[10] Santoro et al. reported that OrthoCAD's tooth width measurements were slightly smaller than those of manual measurements.[7] The magnitude of these differences ranged from 0.16 mm to 0.38 mm and were considered clinically irrelevant.[7] In 2004, Quimby et al. found that OrthoCAD's measurements differed statistically and were found to be slightly larger.[6] Furthermore, there was significantly greater variance associated with measurements made on the computer-based models.[6] Despite this, it was concluded that the accuracy and reliability of OrthoCAD appeared to be clinically acceptable.[6]

In an assessment of the emodel system, Stevens et al. compared plaster casts with digital models for recording tooth widths and performing a Bolton analysis.[2] The reproducibility of digital models using the concordance correlation coefficient was found to be excellent in most cases.[2] Mean tooth width differences ranged from 0.01 to 0.21 mm between the two methods and a half of the results were statistically significant.[2] Emodel measurements were larger and smaller than plaster measurements in almost equal proportions.[2] Bolton anterior and overall ratios were not statistically different (p = 0.790 and p = 0.084, respectively).[2] The authors concluded that emodels were a clinically acceptable replacement of plaster casts for routine orthodontic measurements.[2] Mullen et al. in 2007, assessed the accuracy and speed of performing a Bolton analysis using emodel compared with hand-held plaster models.[11] The results showed that there was no statistically significant difference between the Bolton ratios calculated using the two methods.[11] The mean difference was 0.05 ± 1.87 (p = 0.86).[11] It also took less time to calculate the Bolton ratio using the emodel system by an average of 65.6 seconds.[11] Mullen et al. determined that calculating a Bolton ratio using the emodel system is just as accurate, and significantly faster, than the manual method of using calipers to measure plaster models.[11] In 2010, Horton et al. found that when used to measure mesial-distal tooth widths, the emodel system produced a small positive bias or over-estimation of tooth sizes.[12] However, the authors acknowledged that this bias was small and should not restrict the clinical use of the digital technique.[12]

The first study evaluating DigiModel in measuring tooth widths and performing Bolton analyses was published by Naidu et al. in 2009.[3] The results indicated that DigiModel tended to underestimate mesio-distal tooth widths by an average of 0.08 mm, overestimate the overall Bolton ratio by an average of 0.18% and underestimate the anterior Bolton ratio by an average of 0.43%.[3] The Bolton discrepancies equated to an overall tooth size discrepancy (TSD) of 0.18 mm and an anterior TSD of 0.24 mm, which was considered to be clinically insignificant.[3] The reliability and reproducibility of DigiModel was found to be excellent.[3]

Published research has indicated that the mean discrepancy between digital model and plaster measurements is low.[1] Statistically significant tooth-size differences between the studies has been found to be equivocal.[12] Nevertheless, all studies have considered that the differences were clinically insignificant.[1] Computer models were also deemed to be reliable and reproducible, which has rendered 3D digital models a clinically acceptable substitute for traditional plaster casts.[12]

3D digital models offer a number of advantages:

1. Archiving: Storage space is negligible.[13] Hundreds of models can be stored on a portable hard drive or a DVD.[6] This will solve or alleviate the problems associated with storing plaster casts.[14]
2. Integration: Joffe[15] and Asquith et al.[13] stated that digital models can be easily integrated into a patient's electronic file along with digital photographs, radiographs and clinical notes.
3. Instant retrieval: Retrieval is fast and efficient. Patient records can be accessed instantly via a computer without the need to search and retreive plaster models.[1,2]
4. Viewing: Images can be viewed at multiple locations.[13] In addition, the zoom function exaggerates features that would not normally be noticeable on plaster casts.[2] This may be helpful in detecting extra information.[2] Furthermore, virtual models create no physical barrier in the placement of measurement points or calipers between the teeth.[2] Therefore, provided that landmarks are carefully selected, it is reasonable to accept that digital measurements may be more accurate.[2]
5. Transfer of files: Virtual images may be sent anywhere in the world for instant referral, consultation, or, with permission, for use by internet study clubs.[1,2]
6. Saves money: Monthly storage costs associated with plaster models are avoided.[2]
7. Diagnostic setups: Accurate and simple diagnostic setups of various extraction patterns can be performed.[2]
8. Speed: Proffit et al. emphasised that an advantage of digitising models is the ability of the computer to quickly perform a tooth-size analysis.[16] When calculating Bolton ratios from plaster models, it is necessary to document the measurements and make calculations with either a calculator or computer.[11] However, using computer software, the analysis can be done electronically which creates a digital time advantage.[11]
9. Patient appeal: Zilberman et al. stated that 3D digital models may appeal to patients as modern dental care.[10] Younger patients especially, may relate to the technology.[17]
10. Durability: Durability is a disadvantageous factor related to plaster casts.[12] Through repeated use and measurement, a plaster cast may be damaged or broken.[12] However, digital models can be

virtually manipulated and sectioned without being permanently altered.[12]

3D digital models have several limitations:

1. Lack of tactile input: Digital models cannot be held and assessed in the same way as plaster casts.[7,13]
2. Learning curve: Familiarisation with the appropriate software takes time.[13] The learning curve for the software is often steep but short-lived.[2]
3. 2D viewing: Although the model is 3D, the image can only be viewed on a 2D screen.[13]
4. Failure: Computer failure, software failure, or manufacturer insolvency can possibly mean that the models may become inaccessible.[6]

Intra-oral scanners

The latest introduction to dentistry has been the intra-oral scanner. It is a chair-side unit which allows the clinician to obtain a virtual impression of the patient's oral cavity. Using a handheld camera, the geometry of the dentition can be captured to instantly produce a 3D image of the patient's teeth and occlusion.

In September 2009, Cadent introduced an iOC intra-oral scanner (Figure 3) which uses parallel confocal imaging to digitally record the surfaces and contours of the teeth and gingiva.[18,19] The unit employs a combination of laser and optical scanning to capture information without the need for surface pre-coating with titanium oxide powder.[19]

The iOC scanner offers several advantages:

1. Comfort: Taking conventional impressions can be stressful for the practitioner and uncomfortable for a young patient.[20] Digital impressions can overcome this problem by removing the 'gag factor'.[19]
2. Real-time display: The virtual impression is instantly available for immediate patient and parent consultation and efficient treatment planning.[19]
3. Accuracy: Cadent claims superior accuracy with the iOC scanner.[19]
4. Going green: The environmental 'footprint' of digital impressions is significantly smaller than traditional impressions.[20] The disposal of a substantial volume of plastic impression trays and impression material can be environmentally avoided.[20]
5. Increased productivity: Following digital impressions, surgery preparation is much quicker as there is no impression debris to clean up and no forms or packaging to arrange for laboratory delivery.[21]
6. Cleft lip and palate patients: Asquith and McIntyre stated that the development of intra-oral scanning and 3D digital modelling may offer the potential to eliminate the need for serial impressions during childhood and adolescence, particularly as compliance for impression taking in patients with clefts is reduced.[13]

The iOC system also has disadvantages:

1. Cost: The initial investment cost of the machine is significant and needs to be considered carefully.[20]
2. Learning curve: As with all new technology a learning curve is present.[21] However, Cadent provides in-office training for staff.[19,20] Similarly,

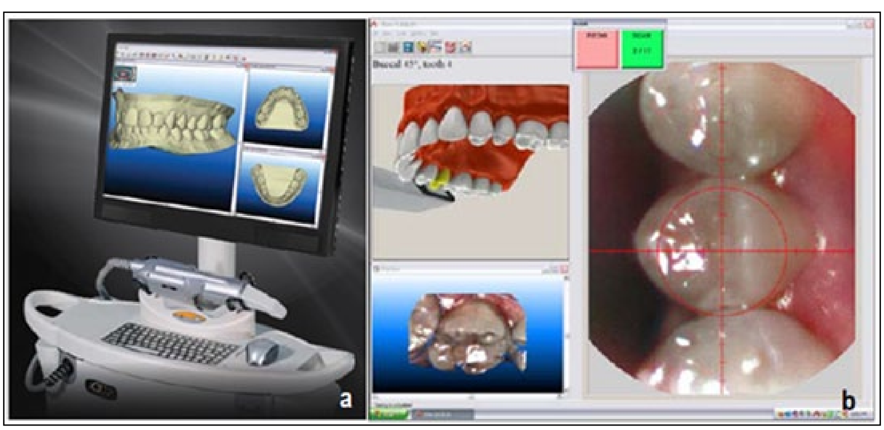

Figure 3. (a) The iOC scanner; (b) during active scanning the area of interest appears on the monitor.[19,21]

Figure 4. The Lythos Digital Impression System.[30]

intuitive software and automated prompts allow the iOC to guide the user through the scanning sequence.[22]

3. Time: According to Cadent, after mastering the technique, full arches can be scanned in 6-8 minutes.[19,22] Within a minute, the system builds a preview 3D model with the teeth articulated.[23]

The only published orthodontic study which has evaluated the use of the iOC scanner was presented by Naidu et al. in 2013. It was found that teeth measured using the iOC/OrthoCAD system were, on average, 0.024 mm larger than those measured with calipers.[24] Although this difference was statistically significant ($p = 0.0083$), it was deemed to be clinically insignificant.[24] Most of the tooth width differences (98.2%) were within 0.5 mm.[24] Furthermore, there was an equal number of overestimates and underestimates of tooth widths, indicating that the 0.024 mm bias was not consistent.[24] The accuracy of the Bolton ratios produced digitally was also judged to be clinically acceptable.[24] The reliability of the system was excellent with replicates strongly correlated ($r = 0.99$), and the intra-class correlation coefficient scores for reproducibility exceeded 87%.[24] The authors concluded that the iOC/OrthoCAD system was a reliable and effective orthodontic aid.[24]

The Lava Chairside Oral Scanner (C.O.S.) (3M ESPE) was released in February 2008.[25,26] The Lava C.O.S. consists of a mobile cart containing a CPU, a touch screen display, and a scanning wand which has a camera at the tip containing 192 blue LED cells and 22 lens systems.[26] Powder coating of the dentition with titanium oxide is necessary for data capture.[27] Active Wavefront Sampling and '3D in Motion' technology are used for recording 3D impressions.[26] The user captures continuous 3D video images to create a virtual impression in real-time on the monitor.[25,28] After scanning, the electronic files are sent via the internet to the company for processing into digital models.[29] These can then be downloaded and subsequently analysed by the orthodontist using the DigiModel software.[29] There is also the option of printing the virtual models as stereolithographic (SLA) casts.[28] SLA models made from epoxy resin can be generated and sent to the clinician if physical copies are required.[29]

Recently, two studies testing the accuracy of the Lava C.O.S. have been published. Cuperus et al. in 2012, compared measurements obtained on digital and SLA models generated from scanning with measurements made on dry human skulls.[29] It was found that of the 44 variables measured, 37 showed statistically significant differences between the skulls and the SLA models and 15 showed statistically significant differences between the skulls and digital models ($p < 0.05$).[29] In general, measurements made on casts produced by an intra-oral scan tended to be smaller than those obtained from skulls.[29] However, the authors concluded that these differences were clinically insignificant and therefore the SLA and digital models were judged to be clinically valid platforms from which to measure dental distances and segments.[29] In 2013, Wiranto et al. found that tooth width measurements made on DigiModels generated with the LAVA C.O.S. were similar to manual measurements made on plaster casts.[27] Although several of the measurements showed statistically significant differences ($p < 0.05$), none of the differences exceeded 0.2 mm and were therefore regarded as clinically acceptable.[27] When used to perform Bolton ratios, the two methods were comparable as none of the Bolton TSDs exceeded 1.5 mm for the entire arch.[27] The authors concluded that the intra-oral scanner is a valid and reliable system for obtaining dental measurements.[27]

The most recently-released scanner is the Lythos Digital Impression System (Ormco) (Figure 4).[30] It was introduced in March 2013.[30] However, there are currently no published studies testing the accuracy of this machine for orthodontic purposes.

Conclusion

Much research has been conducted into the evaluation of digital models. The results of these investigations have generally been positive and show that the accuracy and reliability of digital models are clinically acceptable. The latest device is the intra-oral scanner which shows great promise. However, few studies have been published evaluating its use in orthodontics and so, no meaningful recommendations can currently be made. Therefore, it is concluded that further well-designed studies are needed in this area.

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