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The evidence supporting methods of tooth width measurement: Part I. Vernier calipers to stereophotogrammetry

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Measuring tooth widths is a key component of orthodontic treatment planning. Over recent decades, many methods have been proposed to achieve this purpose. The current review highlights and describes the initial techniques. The evidence behind their use is presented along with a brief discussion of their benefits and shortfalls. With knowledge and understanding of the accuracy and limitations of the various measurement methods, the clinician may be better informed and therefore able to select the most appropriate method for clinical practice.

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Introduction

Measuring tooth widths and performing a Bolton tooth-size analysis is a common task in orthodontic diagnosis and treatment planning. It is desirable to detect any disproportionately-sized teeth early so that they can be appropriately considered in a treatment plan. Various methods have been proposed to provide tooth measurements. However, with the many choices available, confusion exists over the most suitable method to employ. Therefore, the aim of the present paper is to provide an overview of the initial techniques and highlight their accuracy and usefulness.

Vernier calipers

Traditionally, tooth-size analyses have been performed manually on plaster study casts.[1] Mesio-distal tooth widths have been measured using Vernier calipers (Boley gauge) or needlepoint dividers[2,3] which Bolton used in his original article.[4] Shellhart et al. assessed the reliability of a Bolton analysis conducted using these two instruments and found that the Boley gauge was slightly more reliable than needlepoint dividers.[5] Zilberman et al. compared caliper measurements derived from plaster casts with those obtained by removing and measuring artificial teeth from a master setup.[6] The results showed that tooth width readings were highly correlated (R = 0.929 - 0.988) from which the authors concluded that measurements made on study models with calipers were accurate and repeatable.[6] Quimby et al. demonstrated that there was no significant difference ($p > 0.05$) between measurements made manually on plaster casts and those made on an original dentoform setup.[7] The mean discrepancies were within 0.18 mm.[7] Therefore, Vernier calipers are currently regarded as the 'gold standard' for performing tooth width measurements.[2, 8-13]

Holography

Holography uses a laser light to reproduce a 3D image of a dental cast. In 1990, Buschang et al. assessed the accuracy of holograms by comparing tooth width measurements carried out on study casts using calipers, with those carried out on holographic images using a viewer.[14] The results showed that the random errors of measurement on a hologram can be twice as great.[14]

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However, differences in tooth size were not statistically significant.[14] The authors concluded that, when used for quantitative measurements, holograms should be at least as accurate as photocopies and photographs.[14] In 1991, Rossouw et al. used a reflex metrograph to perform measurements on holographic images.[15] A hologram was first constructed using a 25 mW Helium Neon Laser directed at a holographic plate.[15] A reflex metrograph, as described by Takada et al.,[16] was then used to measure 3D co-ordinates on the hologram.[15] Rossouw et al. found that measurements made using this method were comparable with those made with Vernier calipers.[15] Mean measurement differences did not exceed 0.5 mm and the authors concluded that, in principle, holography is a satisfactory and efficient way to record and preserve orthodontic study models.[15]

In 1995, Romeo further discussed the technique of holography and alluded to the storage dilemma faced by orthodontists who have the long-term medico-legal requirement to retain patient records.[17] Holographic films may be the solution to the problem but have limitations. [17] Keating et al. stated that the images were difficult to produce and could not be manipulated as easily as plaster models.[18] In addition, Rossouw et al. acknowledged that the processing and measurement of holograms was intricate and expensive, which may hinder effective clinical use.[15]

Digitised photocopies and scanners

Studies evaluating digitised photocopies and scanned images have yielded mixed results. Yen was the first to introduce a method in which study casts were photocopied and key landmarks digitised.[19] A computer program was subsequently run which displayed tooth-size values and Bolton ratios.[19] Yen stated that, because the direct measurements of a 3D object had the high potential for error and variability, measurements on a 2D transfer were easier and could provide more consistent results.[19] However, following Yen's publication, Champagne determined that photocopies were an unreliable method for arch length measurement and space analysis.[20] In 1997, Schirmer and Wiltshire also evaluated computer-aided space analysis in which models were photocopied using a photostat machine (Xerox, Japan). Mesio-distal tooth sizes were digitised and the results processed with a dedicated computer program.[21] It was found that, when compared with measurements obtained using Vernier calipers, the digitised measurements differed significantly ($p < 0.001$) as 19 of the 24 teeth were recorded as smaller.[21] Hence, it was affirmed that accurate measurements could not be made from photocopies of dental casts.[21] However, in 2006, Paredes et al. re-evaluated digitisation and scanned 100 dental casts.[1] The scanner (Hewlett Packard Scan Jet µc*/T, Houston, TX, USA) was calibrated and tooth sizes measured using a computer mouse.[1] A software program then determined dental sizes in millimetres and automatically calculated the Anterior Bolton Index (ABI) and Overall Bolton Index (OBI).[1] A comparison of tooth widths yielded very low coefficients of variation which indicated that the digital and traditional methods produced similar results.[1] In addition, there was concordance in 90 cases for the ABI, and for the OBI, concordance was found in 97 cases.[1] The discordances were small, and maximum discrepancies of 1.5% for the ABI and 1% for the OBI were judged to be clinically insignificant.[1] Hence, the authors suggested that the proposed digital method was as sensitive and accurate as calipers for calculating Bolton indices.[1]

Digitised photocopies and scanned images offer many advantages. Yen believed that a competent assistant could be trained to digitise the landmarks and generate a space analysis, which saves the orthodontist valuable time.[19] Paredes et al. stated that the use of scanned images to calculate Bolton ratios was faster and easier to perform.[1] The main disadvantage of photocopies and scanned images was their 2D representation of a 3D object.[20] Schirmer and Wiltshire stated that measurement errors may arise from several sources including the convex structure of teeth, the curve of Spee, differences in tooth inclinations, deviations of tooth axes from the perpendicular, and crowded tooth positions.[21]

Digital calipers

Digital calipers have been recently introduced (Figure 1) and these may be linked to a computer for efficient data transfer.[2] Ho and Freer advocated their use to perform tooth width measurements.[22] It was stated that the use of digital calipers with direct input into a computer program can virtually eliminate measurement transfer and calculation errors, compared with analyses which require dividers, rulers and calculators.[22]

Figure 1. Measurement with digital calipers.[33]

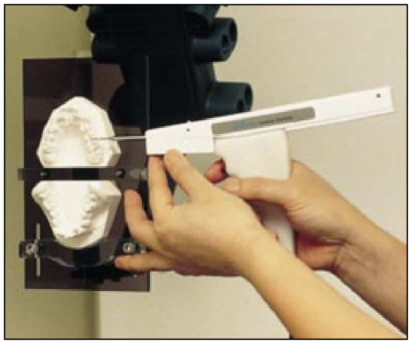

Figure 2. Digitisation on the DigiGraph™ Workstation.[23]

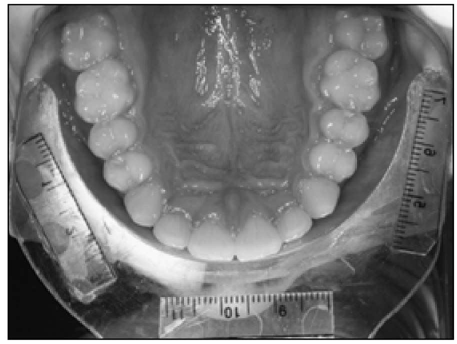

Figure 3. Occlusal photograph with a modified lip retractor.[24]

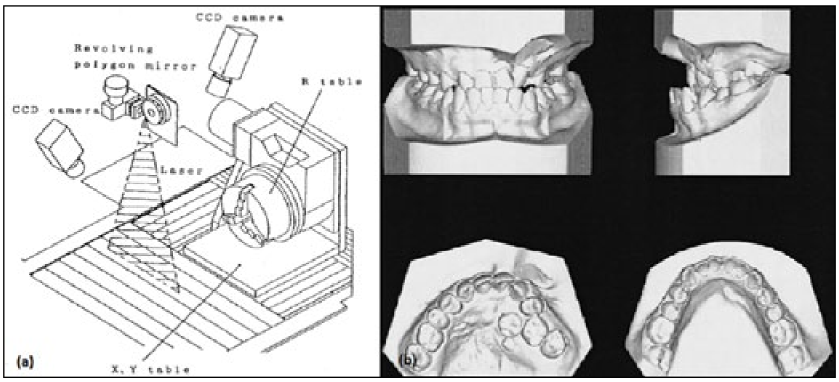

Figure 4. (a) Laser scanning and (b) the generated 3D graphic of the dental model.[25,26]

Sonic digitisation

Mok and Cooke in 1998, evaluated the use of sonic digitisation as a method of measuring tooth widths.[23] Dental casts were placed on a DigiGraph Workstation (DigiGraph, Dolphin Imaging Systems, CA, USA) and digitised.[23] The measurements were taken by positioning the tip of a digitising handpiece on a chosen landmark and pressing a trigger (Figure 2).[23] The results showed that the system consistently over-estimated mesio-distal tooth widths by 1 mm in the mandible and 0.5 mm in the maxilla.[23] Therefore, caution was recommended when using sonic digitisation for space analysis.[23]

Digital photographs

Lowey in 1993, evaluated the IMSCAN method which used a video camera linked to a computer to acquire digital images of study casts.[11] The captured images were displayed on a monitor and arch segments and tooth widths subsequently measured.[11] The results revealed that the IMSCAN method tended to 'over-measure' teeth.[11] Although this was statistically significant, the measurements were clinically comparable with those obtained using calipers.[11] In 2009, Naidu et al. re-evaluated the use of digital photographs of plaster models taken and transferred to a computer for measurement.[8] The results supported those of Lowey[8,11] who indicated that tooth widths tended to be over-estimated (mean - 0.07 mm larger). The difference was statistically significant but the accuracy of digital photographs was still considered to be clinically acceptable.[8] Normando et al. acquired photographs of the dentition with occlusal rulers attached to acrylic retractors (Figure 3).[24] It was found that the photographic measurements had acceptable accuracy for clinical purposes.[24] Eighteen of the 24 tooth width measurements were not statistically different to the caliper recordings.[24] Of the 6 that were, the discrepancy was deemed to be minor (range: 0.13 – 0.33 mm).[24]

Naidu et al. stated that digital photographs offer an advantage as the technology is accepted, readily available, and practitioners are familiar with the basic equipment.[8] Photography is advantageous in situations in which clinicians are assessing isolated populations or patients with orthodontic appliances.[24] However, Lowey identified the curve of Spee as a potential source of error in photographs.[11] It was determined that an exaggerated curve of Spee would under- or over-score tooth width measurements when teeth were below or above the level of calibration, respectively.[11] Two-dimensional images also have inherent visualization limitations as landmarks in crowded arches are easily obscured when viewing a study cast from above.[11] As an example, the inaccurate measurement of a mesially-inclined maxillary canine whose mesial margin is likely obscured to any system which viewed the canine from above (occlusally).[11]

Laser scanning

In 1996, Kuroda et al. introduced a newly-developed 3D dental cast analysing system which used laser scanning.[25] The unit was comprised of a measuring device with a slit-ray laser projector, two sets of video cameras and a personal computer as a controller.[25] The dental cast was scanned with a laser beam and converted into a 3D graphic (Figure 4).[25] Conventional linear and angular measurements were conducted on the model and the measurement error was found to be less than 0.05 mm.[25] In 1999, Motohashi and Kuroda proposed an improved laser scanning method which aimed to eliminate blind sectors. The model was scanned from two different directions by rotating a mounted cast.[26] Lu et al. introduced the inclusion of a semi-conductor laser by which two pulsate motors made movements of the dental cast and allowed 3D data capture anywhere on its surface.[27] The advantages of the system were its precision, simplicity, high efficiency, and the ability to supply new information which could not be generated by other methods.[27] To assess the accuracy of laser scanned casts, Hirogaki et al. in 2001 compared measurements on computer-reconstructed models with those on actual casts.[28] The differences were within 0.3 mm and hence, the laser scanning method was considered to be satisfactory for the purpose of tooth-size analysis.[28] Abizadeh et al. in 2012 evaluated the accuracy of the R250 Scanner (3-Shape, Copenhagen, Denmark) in making measurements of occlusal relationships and arch dimensions.[29] The results showed that the digital recordings tended to be slightly smaller for 11 of the 16 parameters assessed; however, these differences were not clinically relevant.[29]

Stereophotogrammetry

Ayoub et al. in 1997, introduced the technique of stereophotogrammetry.[30] The system involved the use of stereo pairs of video cameras connected to a computer and special coloured illumination to record dental study models in a digital format.[30] In 2003, Bell et al. conducted a study to evaluate the accuracy of this method in measuring dental casts.[31] Measurements of the 3D images were obtained to a precision of 0.27 mm.[31] This difference was within the operator error range of 0.1 - 0.48 mm and was not statistically significant ($p < 0.05$).[31] Therefore, the authors concluded that the photostereometric technique was an accurate and reproducible way of measuring dental study casts. Al-Khatib et al. in 2012, produced similar findings with mean tooth-size differences between direct and 3D stereophotogrammetric measurements ranging from 0.07 – 0.21 mm.[32] Although several statistically significant differences were found, they were considered to be clinically insignificant.[32]

Conclusion

Considerable research has been conducted into different methods of measuring tooth widths and performing Bolton analyses. The traditional method of using Vernier calipers on plaster models is still regarded as the 'gold standard.' Earlier techniques such as holography, digitising photocopies, and sonic digitisation have demonstrated measurement errors. However, more contemporary methods such as the use of digital photographs, laser scanning, and stereophotogrammetry have been shown to be more clinically accurate.

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References

1. Paredes V, Gandia JL, Cibrian R. Determination of Bolton tooth-size ratios by digitization, and comparison with the traditional method. Eur J Orthod 2006;28:120-5.

2. Othman SA, Harradine NW. Tooth-size discrepancy and Bolton's ratios: a literature review. J Orthod 2006;33:45-51; discussion 29.
3. Tomassetti JJ, Taloumis LJ, Denny JM, Fischer JR, Jr. A comparison of 3 computerized Bolton tooth-size analyses with a commonly used method. Angle Orthod 2001;71:351-7.
4. Bolton WA. Disharmony in tooth size and its relation to the analysis and treatment of malocclusion. Am J Orthod 1958;28:113-30.
5. Shellhart WC, Lange DW, Kluemper GT, Hicks EP, Kaplan AL. Reliability of the Bolton tooth-size analysis when applied to crowded dentitions. Angle Orthod 1995;65:327-34.
6. Zilberman O, Huggare JA, Parikakis KA. Evaluation of the validity of tooth size and arch width measurements using conventional and three-dimensional virtual orthodontic models. Angle Orthod 2003;73:301-6.
7. Quimby ML, Vig KW, Rashid RG, Firestone AR. The accuracy and reliability of measurements made on computer-based digital models. Angle Orthod 2004;74:298-303.
8. Naidu D, Scott J, Ong D, Ho CT. Validity, reliability and reproducibility of three methods used to measure tooth widths for Bolton analyses. Aust Orthod J 2009;25:97-103.
9. Stevens DR, Flores-Mir C, Nebbe B, Raboud DW, Heo G, Major PW. Validity, reliability, and reproducibility of plaster vs digital study models: comparison of peer assessment rating and Bolton analysis and their constituent measurements. Am J Orthod Dentofacial Orthop 2006;129:794-803.
10. Santoro M, Galkin S, Teredesai M, Nicolay OF, Cangialosi TJ. Comparison of measurements made on digital and plaster models. Am J Orthod Dentofacial Orthop 2003;124:101-5.
11. Lowey MN. The development of a new method of cephalometric and study cast mensuration with a computer controlled, video image capture system: Part I. Br J Orthod 1993;20:203-14.
12. Santoro M, Ayoub ME, Pardi VA, Cangialosi TJ. Mesiodistal crown dimensions and tooth size discrepancy of the permanent dentition of Dominican Americans. Angle Orthod 2000;70:303-7.
13. Horton HM, Miller JR, Gaillard PR, Larson BE. Technique comparison for efficient orthodontic tooth measurements using digital models. Angle Orthod 2010;80:254-61.
14. Buschang PH, Ceen RF, Schroeder JN. Holographic storage of dental casts. J Clin Orthod 1990;24:308-11.
15. Rossouw PE, Benatar M, Stander I, Wynchank S. A critical comparison of three methods for measuring dental models. J Dent Assoc S Afr 1991;46:223-6.
16. Takada K, Lowe AA, DeCou R. Operational performance of the Reflex Metrograph and its applicability to the three-dimensional analysis of dental casts. Am J Orthod 1983;83:195-9.
17. Romeo A, Canal F, Roma M, de la Higuera B, Ustrell JM, von Arx JD. Holograms in orthodontics: a universal system for the production, development, and illumination of holograms for the storage and analysis of dental casts. Am J Orthod Dentofacial Orthop 1995;108:443-7.
18. Keating PJ, Parker RA, Keane D, Wright L. The holographic storage of study models. Br J Orthod 1984;11:119-25.
19. Yen CH. Computer-aided space analysis. J Clin Orthod 1991;25:236-8.
20. Champagne M. Reliability of measurements from photocopies of study models. J Clin Orthod 1992;26:648-50.
21. Schirmer UR, Wiltshire WA. Manual and computer-aided space analysis: a comparative study. Am J Orthod Dentofacial Orthop 1997;112:676-80.
22. Ho CT, Freer TJ. The graphical analysis of tooth width discrepancy. Aust Orthod J 1994;13:64-70.
23. Mok KH, Cooke MS. Space analysis: a comparison between sonic digitization (DigiGraph Workstation) and the digital caliper. Eur J Orthod 1998;20:653-61.
24. Normando D, da Silva PL, Mendes AM. A clinical photogrammetric method to measure dental arch dimensions and mesio-distal tooth size. Eur J Orthod 2011;33:721-6.
25. Kuroda T, Motohashi N, Tominaga R, Iwata K. Three-dimensional dental cast analyzing system using laser scanning. Am J Orthod Dentofacial Orthop 1996;110:365-9.
26. Motohashi N, Kuroda T. A 3D computer-aided design system applied to diagnosis and treatment planning in orthodontics and orthognathic surgery. Eur J Orthod 1999;21:263-74.
27. Lu P, Li Z, Wang Y, Chen J, Zhao J. The research and development of noncontact 3-D laser dental model measuring and analyzing system. Chin J Dent Res 2000;3:7-14.
28. Hirogaki Y, Sohmura T, Satoh H, Takahashi J, Takada K. Complete 3-D reconstruction of dental cast shape using perceptual grouping. IEEE Trans Med Imaging 2001;20:1093-101.
29. Abizadeh N, Moles DR, O'Neill J, Noar JH. Digital versus plaster study models: how accurate and reproducible are they? J Orthod 2012;39:151-9.
30. Ayoub AF, Wray D, Moos KF, Jin JR, Niblett TB, Urquhart C et al. A three-dimensional imaging system for archiving dental study casts: a preliminary report. Int J Adult Orthodon Orthognath Surg 1997;12:79-84.
31. Bell A, Ayoub AF, Siebert P. Assessment of the accuracy of a three-dimensional imaging system for archiving dental study models. J Orthod 2003;30:219-23.
32. Al-Khatib AR, Rajion ZA, Masudi SM, Hassan R, Townsend GC. Validity and reliability of tooth size and dental arch measurements: a stereo photogrammetric study. Aust Orthod J 2012;28:22-9.
33. Mullen SR, Martin CA, Ngan P, Gladwin M. Accuracy of space analysis with emodels and plaster models. Am J Orthod Dentofacial Orthop 2007;132:346-52.