DIGITAL SOFTWARE FOR ORTHODONTIC RECORDS KEEPING

HEALTH TECHNOLOGY ASSESSMENT SECTION
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DISCLOSURE

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EXECUTIVE SUMMARY

Background

Measuring plaster models by hand is the traditional method of assessing malocclusion. Recent technologic advances now allow the models to be digitalized, measured with software tools, stored electronically, and retrieved with computer. Three dimensional (3D) imaging and modelling have undergone significant advances in recent years, raising the possibility of the development of the ‘virtual orthodontic patient’, where bone, soft tissue and teeth can be recreated in 3D (Quimby et al, 2004). Seven digital model systems were assessed in these trials: OrthoCAD, emodel, C3D-builder, ConoProbe, Easy3D Scan, Digimodels and Cecile 3.

Orthodontic treatment of adult patients with complex dental problems is done by interdisciplinary teams where different specialist of dental medicine has to manage a vast quality of data. In such complicated cases good diagnostic tools and easy communication are essential. Computer science has an increasing impact in almost every aspect of the orthodontic practice, research and education. Orthodontists use computers for digital photographs, virtual study model, cone beam computed tomography, three-dimensional craniofacial, communication, virtual reality, software for prediction and treatment planning, video imaging, manufacture of orthodontic appliance, web based digital orthodontic records and network attached storage device. Computers have become a necessity rather than an option.

This technology review was conducted following a request from an orthodontist from Klinik Pergigian Jalan Abdul Samad, Johor Bahru.

Objective/aim

The objective of this study was to assess the accuracy and reproducibility of digital software for orthodontic records keeping.

Results and conclusions

There were five studies on comparison of computer based digital model and plaster model identified, including a systematic review.

Overall, there was fair level of evidence to show that digital models offer a high degree of validity when compared to direct measurement on plaster models; differences between the approaches are likely to be clinically acceptable/insignificant. Perhaps the most important benefit of using digital models is the ability to share and exchange information effectively, in addition to not having to physically store and manually retrieve the stone models.

These exciting new tools are expected to streamline the orthodontic process even further, elevating orthodontic practices to higher levels of treatment efficacy, efficiency and profitability.

Recommendation
Based on the above review, digital software may be used for orthodontic records keeping. However, the cost and expertise of using the digital software have to be considered. Centralization may be the best option.

Methods
Literature was searched through electronic databases which included MEDLINE, Cochrane Library via Ovid, EMBASE, PubMed and general databases such as Google Scholar.

The search strategy used these terms either singly or in various combinations: dental record, computer assisted, image processing, and dental model.

The search was limited to human study. The last searched was conducted on 24 March 2015.

DIGITAL SOFTWARE FOR ORTHODONTIC RECORDS KEEPING

1. BACKGROUND

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Orthodontic treatment of adult patients with complex dental problems is done in interdisciplinary teams where different specialist of dental medicine has to manage a vast quality of data. In such complicated cases good diagnostic tools and easy communication are essential. Computer science has an increasing impact in almost every aspect of the orthodontic practice, research and education. Orthodontists use computers for digital photographs, virtual study model, cone beam computed tomography, three-dimensional craniofacial, communication, virtual reality, software for prediction and treatment planning, video imaging, manufacture of orthodontic appliance, web based digital orthodontic records and network attached storage device. Computers have become a necessity rather than an option.

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2. OBJECTIVE / AIM

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3. TECHNICAL FEATURES

3.1. Dental plaster model is a three dimensional (3D) reproductions of the teeth and the surrounding soft tissue of a patient's maxillary and mandibular arches. It is also refers to as study or stone casts. Over a century after the introduction of orthodontics as a separate dental discipline, 3D models continue to play an important role in the profession. They are an essential element of the diagnostic record and are used to document the original condition, to plan treatment, and to measure treatment effects. This diagnostic document has its most common applications in clinical practice, clinical research, and medico-legal issues. In practice, 3D models are common items in orthodontic offices all over the world.

Figure 1: Dental plaster model

Until lately, plaster models have been the only way to make 3D models to accurately represent a malocclusion.

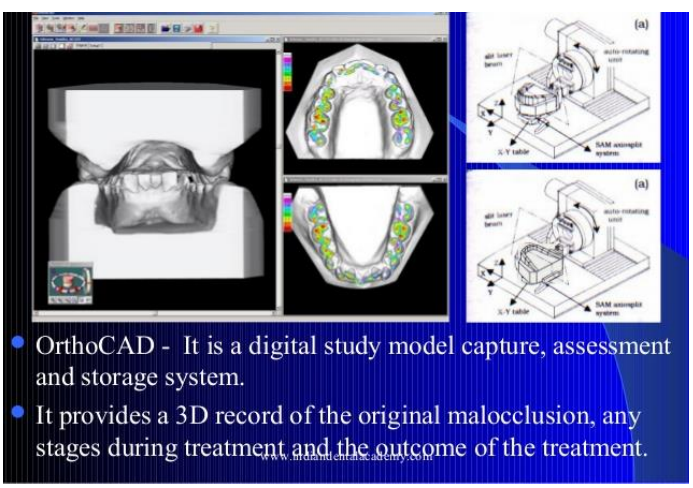

Figure 2: Digitalizing study models using OrthoCAD

Recently, however, digital alternative has become available in the form of 3D computerized models. The idea of 3D virtual orthodontic models seems very promising, if proven to be accurate and trustful. The electronic storage of all patient's information, including study casts, will eliminate problems of storage, retrieval and maintenance of models, office management and communication between different specialties giving the possibility for easier consultation. This alternative will make everyday work more efficient and appeal to the patients as up to date dental care. The potential advantages of digital models for the quantification of orthodontic problems would be negated if the validity, efficiency and ease of linear and angular measurements of occlusal features with digital models were not comparable to those related to plaster models, the current "gold standard" used routinely in clinical practice. Digital models are gaining increasing acceptance as an alternative to traditional plaster models in orthodontics.

To obtain the digital models, users simply send by overnight service alginate impressions and wax bites of their patients' teeth to the OrthoCAD service center. Within a week, models are downloaded automatically (usually at night) via the Internet to their final destination. Users can then store, retrieve, diagnose, and communicate their cases electronically. The system requires 3 basic components: (1) a download utility installed on an Internet-ready PC acting as a gateway, (2) a designated folder for the incoming models, and (3) a 3D browser, allowing the clinician to make use of the digital information. This structure applies to any type of environment, either a stand-alone notebook or a 20-unit, twin-server-based network. In a typical orthodontic office, this means that the models can be accessed from every PC equipped with a 3D browser, if the PC is networked to the designated folder (but not necessarily to the downloading station).

4. METHODS

4.1. Searching

Electronic databases were searched through the Ovid interface: Ovid MEDLINE® In-process and other Non-indexed citations and Ovid MEDLINE® 1948 to present, EBM Reviews - Cochrane Central Register of Controlled Trials – December 2014, EBM Reviews - Cochrane Database of Systematic Reviews - 2005 to March 2015, EBM Reviews - Health Technology Assessment – 1st Quarter 2015, EMBASE – 1988 to 2015 week 12. Searches were also run in PubMed. Google was used to search for additional web-based materials and information. The search was limited to publication year from 2009 to current. No other limits were applied. Additional articles were identified from reviewing the references of retrieved articles. Last search was conducted on 15 April 2015.

Appendix 1 showed the detailed search strategies.

4.2. Selection

A reviewer screened the titles and abstracts against the inclusion and exclusion criteria and then evaluated the selected full text articles for final article selection.

The inclusion and exclusion criteria were:

Inclusion criteria

Problem	Record keeping
Interventions	Computer based digital model
Comparators	Dental plaster model
Outcomes	Accuracy, reproducibility
Study design	Health Technology Assessment, Systematic Reviews, Randomised Controlled Trial (RCT), Non Randomised Controlled Trial, Cohort studies, Cross sectional studies, case series, case reports
	English full text articles

Exclusion criteria

Study design	Studies conducted in animals and narrative reviews
Outcome	Non English full text articles

Relevant articles were critically appraised using Critical Appraisal Skills Programme (CASP) and graded according to US/Canadian preventive services task force (Appendix 2). Data were extracted and summarised in evidence table as in Appendix 3.

5. RESULTS AND DISCUSSION

There were five studies on comparison of computer based digital model and plaster model identified, including a systematic review.

5.1. ACCURACY AND REPRODUCIBILITY

The aim of the systematic review is to evaluate the validity/accuracy of the use of digital models to assess tooth size, arch length, irregularity index, arch width and crowding versus measurements generated on hand-held plaster models with digital callipers in patients with and without malocclusion.

Comparisons between measurements of digital and plaster models made directly within studies were reported, and the difference between the (repeated) measurement means for digital and plaster models were considered as an estimates. Seventeen relevant studies were included. Outcomes assessed included the validity of analysis of transverse dimensions, other miscellaneous linear measurements, tooth size, Bolton ratio, arch length and crowding, irregularity index, inter-arch occlusal features, occlusal indices, and time taken to perform measurements using the two approaches.

Forty abstracts were considered potentially relevant. Following screening, 29 full-text articles were retrieved. Of these, 12 failed to meet the inclusion criteria. A hand search of references in the 14 articles satisfying the inclusion criteria identified three additional articles. Therefore, 17 articles were included in the review.

Seven digital model systems were assessed in these trials: OrthoCAD, emodel, C3D-builder, ConoProbe, Easy3D Scan, Digimodels and Cecile 3. Agreement between recordings on OrthoCAD and plaster models was assessed in nine studies, between emodels and plaster models in three investigations and using the other software systems in a single study each.

i) Transverse dimensional measurements

The agreement between transverse dimensional readings obtained using digital and plaster models has been assessed in three studies. Dimensions considered include mandibular and maxillary inter-canine, inter-premolar and inter-molar dimensions. Mean discrepancies between the approaches ranged from 0.04 to 0.4 mm. Generally, these differences were small and unlikely to be of clinical significance. [1 Level I]

ii) Miscellaneous linear measurements

The reliability of non-specific measurements between various defined occlusal landmarks with both sagittal and transverse components was investigated by Bell et al and Keating et al in the systematic review. These studies described similar levels of consistency with mean discrepancies of 0.14 and 0.27 mm reported, respectively. Consequently, combinations of antero-posterior and transverse measurements appear to have similar reliability as purely transverse or sagittal measurements. [1 Level I]

iii) Tooth size

Differences in individual tooth size with digital and direct methods have been measured in the mesio-distal and vertical dimension. Tooth size has also been used indirectly to calculate Bolton tooth size ratios, arch length and tooth size-arch length discrepancy. Generally, minor mean differences in mesio-distal tooth dimension of 0.01 to 0.3 mm were reported overall.

Measurement of vertical crown height is likely to be imprecise with identification of a cervical point particularly unreliable. In the systematic review, Keating et al assesses vertical crown heights of premolars and molars using the maximum point of concavity on the labial surface gingival margin as the cervical reference point; a difference in the measurement of canine and molar heights of 0.1 mm was detected. [1 Level I]

iv) Bolton ratio

In the systematic review, comparison of Bolton tooth size analyses has been performed on digital and plaster models by Tomassetti et al; Stevens et al and Mullen et al. Acceptable agreement between the two methods was demonstrated in all three studies. Stevens et al described an anterior discrepancy of 0.6 mm; however, Mullen et al reported an overall mean difference of just 0.05 mm. Stevens et al found an overall discrepancy of 0.38 mm using e-models; Tomassetti et al found a more significance difference of 1.02 to 1.2 mm between direct measurement on plaster models and digital measurement using OrthoCAD. [1 Level I]

v) Space analysis, arch-length and tooth size-arch length discrepancy (crowding)

Overall, arch length, crowding and space analysis were measured in five studies of the systematic review which are Quimby et al; Stevens et al; Redlich et al; Goonewardene et al and Leifert et al. With respect to arch length, discrepancies between the techniques ranged from 0.19 (Redlich et al) to 0.8 mm (Goonewardene et al). The difference between the measurement of crowding obtained with the techniques varied from 0.19 mm (Goonewardene et al) to 0.42 mm (Leifert et al); however, the mean degree of crowding in each trial did not exceed 4.69 mm (Leifert et al), with the arches being spaced in one of the studies (Goonewardene et al). [1 Level I]

vi) Irregularity index

The irregularity index in both the maxillary and mandibular arches was measured by Goonewardene et al. Identical mean levels of irregularity were calculated with both techniques using OrthoCAD digital models. However, using e-models, Stevens et al reported a significant discrepancy with the digital software underestimating irregularity by 3.7 mm. [1 Level I]

vii) Inter-arch occlusal features

In the systematic review, agreement between measurement of overjet and overbite has been considered in four studies which included Santoro et al, Quimy et al; Stevens et al and Kanno et al. Quimby et al and Watanabe-

Kanno et al reported near-perfect agreement for both parameters; similarly, Santoro et al and Stevens et al showed excellent agreement for overjet measurement. The concordance of measurement of posterior cross-bite and center line discrepancy was confirmed by Stevens et al Inter-arch features including buccal segment interdigitation, overbite and overjet are also considered as part of occlusal including PAR, ICON and ABO scoring. [1 Level I]

viii) Occlusal Indices

Acceptable concordance with digital and plaster models in relation to the severity of malocclusion using PAR, ICON and ABO scores has been demonstrated. The agreement between manual and digital measurements was high with respect to both PAR by Mayers et al; Stevens et al and ICON by Veenema et al. In relation to the ABO score, three studies by Costalos et al; Okunami et al; Hildebrand at al reported comparisons between the techniques. In general, the differences between the measurements are low; however, Okunami et al and Costalos et al reported a significant discrepancy with respect to occlusal contact and buccolingual inclination scores. Furthermore, Costalos et al reported a significant difference in arch irregularity. These discrepancies were attributed to limitations pertaining to one software program (OrthoCad); the ABO method of measuring inclination is also difficult to apply to digital models. [1 Level I]

ix) Time taken

The difference in the time required to perform a variety of occlusal measurements has been assessed in three disparate studies by Tomassetti et al; Mullen et al and Horton et al. These studies suggest a significant time saving with digital techniques although a significant learning curve and period of adjustment are likely to be required. Relatively minor differences were described by Horton et al (2 minutes) and Mullen et al (1 minute). The approach to digital measurement is also believed to have an impact, with manipulation of the model being necessary to perform specific measurements. Differences may also arise in view of software and familiarity with the technique; Mullen et al measured time take to calculate tooth dimensions in isolation, and calculated tooth size ratios. [1 Level I]

Table 1. Summary of Results of Comparison between Digital Models and Plaster Models

Study	N	Measurement	Digital Model Mean (SD)	Plaster model Mean (SD)	Mean Difference$^{\times}$ (p value, SE or CI)	Average of absolute mean differences$^{\times}$ (SD)
Transverse dimensions (mm)						
Quimby et al.,	1000	Maxillary IMW Maxillary ICW Mandibular IMW Mandibular ICW	54.72 (0.85) 36.04 (0.51) 47.42 (0.52) 26.31 (0.27)	54.43 (0.26) 36.44 (0.26) 47.38 (0.33) 26.65 (0.24)	0.29 (p<0.05) -0.4 (p<0.05) 0.04 (p<0.05) -0.34 (p<0.05)	
Keating et al.,	60	ICW/IPMW/IMW			P = 0.765	0.19 (0.12)
Watanabe-Kanno et al.,	30	Maxillary ICW Maxilarry IPMW Maxillary IMW Mandibular ICW Mandibular IPMW Mandibular IMW	34.23 (1.78) 34.52 (2.01) 44.83 (2.54) 26.57 (1.57) 28.73 (1.86) 39.66 (2.25)	34.35 (1.78) 34.63 (2.02) 44.99 (2.54) 26.71 (1.58) 28.86 (1.85) 39.78 (2.25)		
Miscellaneous linear measurement (mm)						
Bell et al.,	176	Various transverse and sagittal measurements			p>0.05	0.27 (0.06)
Keating et al.,	60	Y plane: Combined transverse and sagittal dimensions			p = 0.501	0.14 (0.09)
Tooth size (mm)						
Santoro et al.,	40	Overall mean			p<0.01	-0.252
Redich et al.,	90	Maxillary mean Mandibullar mean	7.73 (0.01) 7.1 (0.1)	7.7 (0.12) 7.11 (0.1)	0.03 (p>0.05) 0.03 (p>0.05)	
Goonewardene et al.,	50	Maxillary overall Mandibular overall	76.1 (3.61) 66.3 (3.22)	74.8 (4) 65.7 (3.55)	1.3 0.6	
Watanabe-Kanno et al.,	30	Maxillary overall Mandibular overall	8.76 (0.63) 9.9 (0.46)	8.94 (0.63) 10.1 (0.46)	-0.18 (p=0.6) -0.2 (p=0.00)	
Horton et al	96	Overall Difference			1.163 (0.115 per tooth)	
Keating et al.,	60	Crown height			0.03(p=0.218)	0.1 (0.07)
Bolton ratio (mm)						
Tomassetti et al.,	66	Anterior			1.02(p=0.243)	0.60 (0.38)

		Overall			1.2 (p=0.718)	0.92 (0.58)
Stevens et al.,	360	Anterior Overall	-0.55 (2.00) -0.75 (2.64)	-0.51 (1.80) -0.37 (2.20)	-0.04 (p=0.790)	
Mullen et al.,	30	Overall			-0.05 (SE, 1.87; p=0.86)	
Space analysis, arch length and tooth size-arch length discrepancy (crowding) (mm)						
Quimby et al.,	1000	Maxillary space available	74.87 (1.06)	73.58 (0.45)	0.29 (p<0.05)	
		Maxillary space required	73.69 (0.93)	73 (0.37)	0.69 (p<0.05)	
		Mandibular space available	65.71 (0.74)	64.02 (0.43)	1.69 (p<0.05)	
		Mandibular space required	63.85 (0.86)	63.24 (0.49)	0.61 (p<0.05)	
Stevens et al.,	360	Maxillary arch length	94.58 (5.25)	94.78 (5.33)	-0.20 (p=0.226)	0.69 (0.43)
		Mandibular arch length	87.16 (5.44)	86.96 (5.17)	0.20 (p=0.256)	0.65 (0.55)
Mullen et al.,	30	Maxillary arch length Mandibular arch length			1.47 (SE, 1.55; p<0.0001) 1.5 (SE, 1.36; p<0.0001)	
Redlich et al.,	90	Maxillary arch length	73.45 (1.26)	73.64 (1.64)	-0.19 (p>0.05)	
		Mandibular arch length	64.18 (1.29)	64.88 (1.22)	-0.7 (p>0.05)	
		Maxillary crowding	1.41 (0.91)	1.77 (1.01)	-0.26 (p>0.05)	
		Mandibular crowding	0.3 (0.92)	0.71 (0.92)	-0.41 (p>0.05)	
Goonewardene et al.,	50	Maxillary arch length	75.8 (4.32)	74.8 (4.24)	1.0 (p<0.001)	
		Mandibular arch length	65.9 (3)	65.1 (3.28)	0.8 (p=0.007)	
		Maxillary crowding			-0.19 (SE=0.219; p=0.38)	
		Mandibular crowding			1.19 (SE=0.23; p-<0.000)	
Leifert et al.,	50	Maxillary crowding	4.27 (2.41)	4.69 (2.46)	-0.424 (SE=0.16; p=0.014)	
		Mandibular crowding	3.69 (3)	3.9 (3.09)	-0.212 (SE=0.23; p=0.364)	
Irregularity index (mm)						
Stevens et al.,	360	Overall	23.7 (7.81)	20.99 (7.47)	2.71 (p=.003)	3.7 (3.05)
Goonewardene et al.,	50	Maxillary Mandibular	7.8 (4.89) 7.1 (3.07)	7.8 (5.09) 7.1 (3.19)	0.0 (p=0.73) 0.0 (p=0.13)	
Inter-arch occlusal features (mm)						
Stevens et al.,	360	Centreline Posterior	1.23.04) 0.75 (1.86)	1.32 (1.1) 0.74 (1.84)	-0.1 (p=0.30) 0.01 (p=0.747)	

		crossbite				
		Anterior crossbite	0.63 (0.98)	0.67 (1.09)	-0.03 (p=0.59)	
Santoro et al.,	40	Overjet			p=0.9771	-0.00987
Quimby et al.,	1000		1.41 (0.4)	1.4 (0.21)	0.01 (p>0.05)	
Stevens et al.,	360		4.91 (2.98)	4.9 (2.97)	0.01 (p=0.884)	0.33 (0.21)
Watanabe-Kanno et al.,	30		5.22 (2.24)	5.43 (2.24)	-0.21 (p=0.00)	
Santoro et al.,	40	Overbite			p=0.0124	-0.4901
Quimby et al.,	1000		1.45 (0.53)	1.48 (0.3)	-0.03	
Stevens et al.,	360		3.67 (1.82)	3.96 (1.75)	-0.3 (p=0.01)	
Watanabe-Kanno et al.,	30		3.2 (1.32)		-0.31(p=0.00)	
Occlusal indices						
Veenama et al.,	60	Total ICON score	10.97 (2.47) 4.13 (1.31)	11.47 (2.37) 3.4 (1.07)	-0.5 0.73 (p<0.01)	3.7 (3.05)
Mayers et al.,	96	Overall PAR	27.25 (11.49)	27.35 (12.75)	-0.1 (ICC=0.96-0.98)	
Stevens et al	360	score	25.91 (8.79)	25.08 (9.3)	0.83 (p=0.128)	2.11 (1.62)
Time taken (min)						
Tomassetti et al.,	66	Bolton analysis	5.37 (0.87)	8.06 (0.54)	-2.69	
Mullen et al.,	30	Bolton analysis score			p<0.001	1.09 (47)
					0.83 (p=0.128)	2.11 (1.62)
Horton et al.,	96	Occlusal view technique			-2.02	

Footnote: N=number of determinations;
ˣ Negative values represent smaller values on digital models;
ICW, inter-canine width; IPMW, inter-premolar width; IMW, Inter-molar width.
PAR, Peer Assessment Rating.

Zilberman et al evaluate the validity of tooth size and arch width measurements using conventional and three dimensional virtual orthodontic models. The purpose of this study was to test the accuracy of measuring casts with the aid of callipers or OrthoCAD and compare these two techniques. Twenty setups using artificial teeth corresponding to various malocclusions were created. Impressions were taken of them, providing 20 plaster and 20 virtual orthodontic models. Measurements of mesiodistal tooth dimension as well as inter-canine and inter-molar width were made on both. Additionally, values of tooth size were calculated from the isolated artificial teeth removed from the setups and of arch width from the existing setups. The resulting values were compared by the use of non-parametric statistics, and methods' errors were also calculated. Results showed the methods being highly valid and reproducible for both tooth size and arch width. For the tested clinically applicable methods, measurement with digital callipers on plaster models showed the highest accuracy and reproducibility, closely followed by OrthoCAD. Digital callipers seem to be more suitable instrument for scientific work. However, OrtoCAD's accuracy is clinically acceptable, and most likely, considering its present advantages and future possibilities, the examined or an equivalent 3D virtual models' procedure would become the standard for orthodontic clinical use.[2 Level II-2]

Ogodescu et al scanned a total number of 227 teeth using an optical three dimensional scanner (Activity 101, Firma Smart Optics Sensortechnik GMbH, Germany). The measurements on the 3D models were performed using the OnyxCeph^{3TM} software developed by the Firma Image Instruments GmbH, Germany. All of the teeth have no inter-proximal caries, restoration or stripping and no evident tooth wear. The same teeth were measured on the scanned plaster models with a digital calliper by the same investigator. The teeth were measured from occlusal and facial view. After performing statistical analysis (Student's *t* test for paired data), they are no major differences between the measurements carried on digital and plaster models. Digital models can be used in conjunction with CAD-CAM technologies to individualize the brackets to the adult patients crown morphology. Three dimensional databases from digital models and virtual model analysis are useful tools for diagnosis and treatment planning but also for education and research, facilitating statistical analysis. After photography and models the introduction of digital radiography is another important digital tool in the actual concept of virtual reality in orthodontics. In this study, like in many others from the recent orthodontic literature about digital models, found that the measurements of dental dimensions by the software package were very precise, and this is probably the truth at almost all quantitative orthodontic software.[3 Level II-2]

Marines et al evaluate the accuracy and reproducibility of measurements made on 3-dimensional digital models obtained with a surface laser scanner, 3Shape D-250 3-dimensional scanner. Three dimensional images were obtained on this scanner and analyzed by using the Geomagic Studio 5 software (Raindrop Geomagic, Inc,Morrisville, NC). Measurements were made with a digital calliper directly on the dental casts and also digitally on the digital models. Fifteen anatomic dental points were identified, and a total of eleven linear measurements were taken from each cast, including arch length and width. Dependent *t* test were used to evaluate intra-examiner reproducibility and measurement accuracy on the digital models. No statistically significant differences were found between the measurements made directly on the dental casts and on the digital models. Linear measurements on digital models are accurate and reproducible. Digital models obtained with the surface laser scanner are reliable for measurements of arch width and length. Digital models can be used for storing cast models and for research with satisfactory degrees of accuracy and reproducibility of linear measurements.[4 Level II-2]

Bootvong et al assessed the feasibility of virtual models as an alternative to orthodontic plaster models. Virtual dental models (obtained from OrthoCAD) and corresponding plaster models of 80 patients in the permanent dentition were randomly selected from patients seeking orthodontic care. Inter-examiner error was assessed by measuring tooth width, overjet, overbite, inter-molar width, inter-canine width, and midline discrepancy. Criterion validity of virtual model analysis was determined by the agreement between the measurements from virtual and plaster models. Test-retest reliability was determined by re-measuring ten virtual models one week later. Comparison analysis was assessed by calculating the mean directional differences and standardized directional differences. Correlation analysis was determined by calculating the intra-class correlation coefficients (ICCs). Both intra- and inter-examiner reliability and test-retest reliability of virtual model analysis were acceptable in measuring inter-canine, inter-molar, overjet, overbite, midline discrepancy, space analysis, and tooth width (ICC > 0.7). Good criterion validity was indicated by agreement between the results from the plaster and virtual models (ICC > 0.8). There were substantial agreements for canine and molar relationship classifications ($\kappa > 0.7$). The results suggest that analysis performed on virtual models is as valid as traditional plaster models for intra- and inter-arch relationship.[5 Level II-1]

5.2. COST EFFECTIVENESS

The cost of the OrthoCAD scanner is USD 35,600.00 (RM 135,260) which includes the hardware, software, installation, shippin, training and 3 years warranty.[6] For OrthoCAD, a single set of models (upper and lower) typically requires 3 MB of disk space; thus, all storage options, except for floopy disks (1.44 MB), apply. Consequently, a 650 MB compact disk costing less than $1 can hold over 200 models. Similarly, a 20 GB hard drive costing $150 can hold more than 6000 cases. Thus, the lifetime storage costs of the models are negligible.[5 Level II-1]

5.3. LIMITATIONS

This technology review has several limitations. The selection of studies was done by one reviewer. Although there was no restriction in language during the search but only English full text articles were included in this report.

6. CONCLUSION

Overall, there was fair level evidence indicating digital models offer a high degree of validity when compared to direct measurement on plaster models; differences between the approaches are likely to be clinically acceptable/insignificant. Perhaps the most important benefit of using digital models is the ability to share and exchange information effectively, in addition to not having to physically store and manually retrieve the stone models.

These exciting new tools are expected to streamline the orthodontic process even further, elevating orthodontic practices to higher levels of treatment efficacy, efficiency and profitability.

7. REFERENCES

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8. APPENDIX

8.1. Appendix 1: LITERATURE SEARCH STRATEGY

Ovid MEDLINE® In-process & other Non-Indexed citations and OvidMEDLINE® 1948 to present

1. Dental record/
2. (dental adj1 record*).tw.
3. 1 or 2
4. Image processing/
5. computer assisted/
6. (image adj1 reconstruction*).tw.
7. (image analys* adj1 (computer assisted or computer-assisted)).tw.
8. analysis computer-assisted image.tw.
9. (image processing adj1 (computer-assisted or computer assisted)).tw.
10. 4 or 5 or 6 or 7 or 8 or 9
11. Dental models/
12. (dental adj1 model*).tw.
13. 11 or 12
14. 3 and 10 and 13
15. limit to human and English

OTHER DATABASES	
EBM Reviews - Cochrane Central Register of Controlled Trials	Same MeSH, keywords, limits used as per MEDLINE search
EBM Reviews - Cochrane database of systematic reviews	
EBM Reviews - Health Technology Assessment	
EMBASE	

PubMed

Search ((((((((dental record/[Mesh Terms]) AND (((image process* [Title/Abstract]) OR computer assist* [Title/Abstract] OR computer-assist* [Title/Abstract] OR image reconstruct* [Title/Abstract] OR image analys* [Title/Abstract] AND ((((dental model* [Title/Abstract]) OR analysis computer-assisted image [Title/Abstract]

Appendix 2

DESIGNATION OF LEVELS OF EVIDENCE

I Evidence obtained from at least one properly designed randomized controlled trial.

II-I Evidence obtained from well-designed controlled trials without randomization.

II-2 Evidence obtained from well-designed cohort or case-control analytic studies, preferably from more than one centre or research group.

II-3 Evidence obtained from multiple time series with or without the intervention. Dramatic results in uncontrolled experiments (such as the results of the introduction of penicillin treatment in the 1940s) could also be regarded as this type of evidence.

III Opinions or respected authorities, based on clinical experience; descriptive studies and case reports; or reports of expert committees.

SOURCE: US/CANADIAN PREVENTIVE SERVICES TASK FORCE (Harris S2001)

Appendix 3

Evidence Table : **Accuracy and reproducibility**

Question: **Is 3-dimensional digital model measurements are accuracy and reproducibility compared with measurements generated on hand-held plaster models with digital callipers?**

Bibliographic citation	**Study Type / Methodology**	**LE**	**Number of patients and patient characteristics**	**Intervention**	**Comparison**	**Outcome measures/ Effect size**
Fleming PS, Marinho V, Johal A. Orthodontic measurements on digital study models compared with plaster models. A systematic review. Orthod Craniofac Res. 2011; 14:1-16. Santoro *et al.,2003* Bell *et al.,2003* Quimby *et al.,2004* Mayers *et al.,2005* Costalos *et al.,2005* Stevens *et al.,2006* Mullen *et al.,2007* Okunami *et al.,2007* Redlich *et al.,2008* Hilderbrand *et al.,* 2008 Goonwardene *et al.,2008* Keating *et al.,2008* Veenema *et al.,2009* Leifert *et al.,2009* Watanabe-Kanno *et al.,2009* Horton *et al.,2010* Mok *et al.,2007*	Systematic Review	I-1	17 studies to evaluate the validity/accuracy of the use of digital models to assess tooth size, arch length, irregularity index, arch width and crowding versus measurements generated on hand-held plaster models with digital callipers in patient with and without malocclusion. Total up involved 537 subjects	OrthoCAD C3D Builder Emodels Conoprobe 3 Shape D-250 3D Scanner	Digital callipers	Bolton ratio; Time taken Tooth size, overjet, overbite Transverse and sagittal linear measurement Tooth size, Arch length, transverse dimensions, overjet, Overbite, Space available, Space required PAR score ABO score Bolton ratio, time taken Linear dimension (x, y, z planes) Incisors, Canines, Premolar and Molars ICON score Crowding

Evidence Table : **Accuracy and reproducibility**

Question: **Is 3-dimensional digital model measurements are accuracy and reproducibility compared with measurements generated on hand-held plaster models with digital callipers?**

Bibliographic citation	Study Type / Methodology	LE	Number of patients and patient characteristics	Intervention	Comparison	Outcome measures/ Effect size
Marines *et al.*, Accuracy and reproducibility of 3-dimensional digital model measurements. *Am J Orthod Dentofacial Orthop*. 2012. 142: 269-273.	Prospective study in Brazil	II-2	20 subjects, patients with Class 1 and 2 malocclusions, with severe dental crowding, treated with pre-molar extractions	3 Shape D-250 3D scanner	Digital calliper	Arch widths and lengths

Evidence Table : **Accuracy and reproducibility**

Question: **Is 3-dimensional digital model measurements are accuracy and reproducibility compared with measurements generated on hand-held plaster models with digital callipers?**

Bibliographic citation	Study Type / Methodology	LE	Number of patients and patient characteristics	Intervention	Comparison	Outcome measures/ Effect size
Zilbermen *et al.,* Evaluation of the validity of tooth size and arch width measurements using conventional and three dimensional virtual orthodontic models. *Angle Orthodontist*. 2003.73 (3): 301-306	Prospective study in Sweden	II-2	20 setups were created by using 10 sets of artificial teeth more than once	OrthoCAD	Digital calliper	Tooth size and arch width

Evidence Table : **Accuracy and reproducibility**

Question: **Is 3-dimensional digital model measurements are accuracy and reproducibility compared with measurements generated on hand-held plaster models with digital callipers?**

Bibliographic citation	Study Type / Methodology	LE	Number of patients and patient characteristics	Intervention	Comparison	Outcome measures/ Effect size
Ogodescu AS, Sinescu C, Ogodescu EA. Computer science in the orthodontic treatment of adult patients. Advances in Communications, Computers, Systems, Circuits and Devices. 2010. pp. 15-18.	Prospective study in German	II-2	Scanned 227 teeth	OnyxCeph™	Digital calliper	3D models of the teeth

Evidence Table : **Accuracy and reproducibility**

Question: **Is 3-dimensional digital model measurements are accuracy and reproducibility compared with measurements generated on hand-held plaster models with digital callipers?**

Bibliographic citation	Study Type / Methodology	LE	Number of patients and patient characteristics	Intervention	Comparison	Outcome measures/ Effect size
Bootvong K, Liu Z, McGrath C, *et al.* Virtual model analysis as an alternative approach to plaster model analysis: Reliability and validity. European journal of Orthodontics. 2010; 32: 589-595	Prospective study in German	II-2	80 patients in the permanent dentition were randomly selected from patients seeking orthodontic care	OrthoCAD	Digital calliper	Tooth width, overjet, overbite, inter-molar width, inter-canine width, midline discrepancy