Hong Kong Dental Journal 2006;3:107-15

The uses of orthodontic study models in diagnosis and treatment planning

Huie-Ming Hou *, BDS
Ricky Wing-Kit Wong *, BDS, MOrth, PhD, MOrthRCS, FRACDS, FHKAM (Dental Surgery), FCDSHK (Orthodontics)
Urban Hägg *, DDS, OdontDr, CertCompOrth, FDSRCS (Edin), FHKAM (Dental Surgery), FCDSHK (Orthodontics)

ABSTRACT Study casts are the only non-invasive three-dimensional records that provide information which is important for orthodontic diagnosis and treatment planning. This article provides an overview of the use of study casts in orthodontics. Various methods of space analysis, relevant information that can be obtained from study casts and their limitations are elaborated. However, special attention and techniques are required in order to fully utilize the study casts. It should be emphasized that study models are absolutely essential as starting and finishing records in orthodontic treatments, apart from constituting critical medico-legal evidence. Not having starting study models could be a ground for allegations of negligence.

Introduction

Orthodontic diagnostic records are taken to: (1) document the starting point or patient's initial condition and (2) supplement the information gathered during clinical interview and examination [1]. The records can be divided into three categories: study casts, photographs, and radiographs [2]. These are important medico-legal 'documents' that should be obtained even for the simplest forms of procedures, and form the basis for planning orthodontic treatment. This article attempts to introduce some of the uses of study casts in the planning of orthodontic treatment.

For orthodontic diagnosis, we need to ascertain the shape and size of the teeth; their positions and the extent of crowding/spacing of teeth within the jaw; their occlusal relationships and the results of other special investigations.

* Faculty of Dentistry, The University of Hong Kong, Hong Kong

Correspondence to:
Dr. Ricky Wing-Kit Wong
Faculty of Dentistry, The University of Hong Kong,
34 Hospital Road, Hong Kong
Tel : (852) 2859 0554
Fax : (852) 2559 3803
e-mail : fyoung@hkucc.hku.hk

Tooth number, shape, size, position and space analyses

Tooth number

Failure to count the teeth is a common mistake [3]; counting must include those that are visible as well as those developing within or outside the jaws (as revealed by radiographs). Congenital absence of teeth should also be noted.

Tooth shape

Study casts provide a very clear view for the clinician to assess dental crown morphology and anatomy. Tooth anomalies can be classified as arising from: tooth formation, eruption, and alignment [4]. It is not unusual to find shovel-shaped or peg-shaped incisors, dens evaginatus and invaginatus, talon cusps, double teeth, Carabelli's traits, and other anomalies of dentition [5]. These unusual morphologies will affect dental occlusion as well as the tooth size discrepancy.

Such unusual dental morphology can affect the extraction choice during treatment planning. For example, dens evaginatus commonly affects premolar teeth of orientals. The reported prevalence of dens evaginatus was 3% in 12-year-old Hong Kong Chinese [6] and 2.1% in 10-year-old Singaporeans [7]. Fracture or attrition of the tubercle of dens evaginatus may result in an enamel

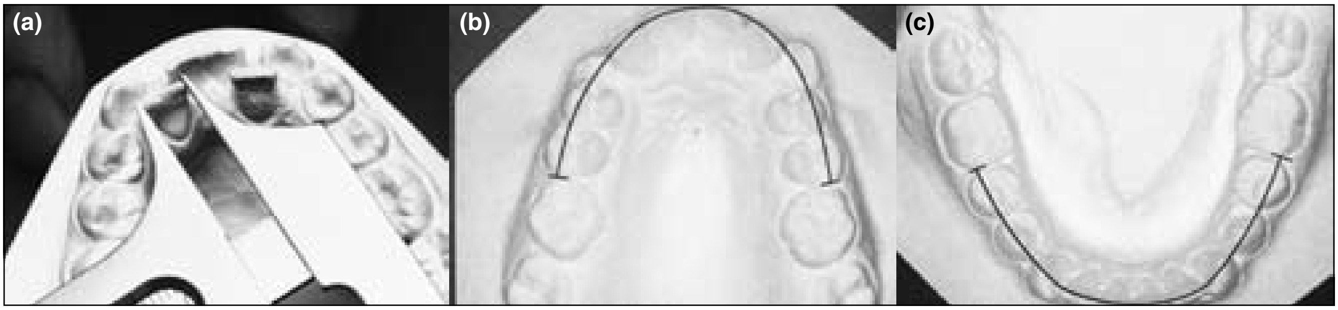

Figure 1 (a) Measurement of tooth width. (b) Upper arch and (c) lower arch for measuring arch length

defect and/or exposure of the pulp; thus, pulpal inflammation and necrosis may occur before or after complete root formation [8].

Tooth size and space

Study casts are very useful in assessing the relationship between the tooth size and the size of supporting structures, which can be based on the space analysis technique.

According to Kirschen *et al* [9], such space analysis can assist clinicians in various aspects of diagnosis and treatment planning. In principle the analysis depends on comparing the space required for alignment of the teeth and the actual space available. The space analysis method suggested by Nance [10] was carried out by:

(1) Measuring the mesiodistal width of each tooth mesial to the first permanent molar. The total sum of the mesiodistal width corresponds to the space required for the alignment of teeth (Figure 1a).
(2) Measuring the actual arch length by contouring a soft wire to the individual arch shape over the contact points of posterior teeth and the incisal edges of the anteriors (Figures 1b and 1c). The distance of the straightened wire is the available space for the alignment of teeth. Another method divides the dental arch into four segments: from mesial aspect of the first permanent molar to the distal aspect of the canine of the same side; then to mesial of centrals: then to distal of canine of the other side; then to mesial of first permanent molar of the other side. Arch length can be measured as straight line approximations of the arch [1].

Space analysis in mixed dentition

As the permanent teeth are not fully erupted during the mixed dentition stage, estimation of the unerupted permanent teeth is necessary for the mixed dentition space analysis. The aim is to compare the space available for the unerupted permanent canine and premolars with the space needed, the difference is then the amount of crowding, or of spacing, present. The following is the method used in the Orthodontics Department in the University of Hong Kong.

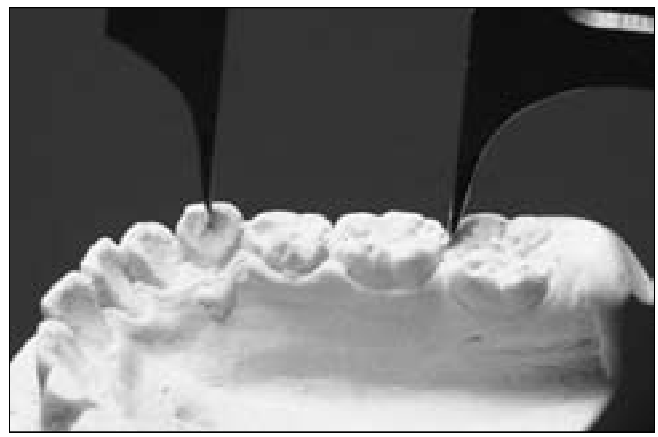

Figure 2 The estimated position of distal surface of lateral incisor (with lower incisors aligned) is marked on the lingual surface of lower canine. This mark is used for measurement of the space available for permanent canine and premolars

To measure the space available, mark the distance, in the line of the arch, that is needed for the alignment of the central and lateral incisors. This distance shows how much of the arch perimeter will be taken up during alignment of the mandibular incisors. If the teeth are well aligned, no correction is needed. Repeat for both sides.

Now measure the space available for the unerupted canines and premolars. This is the distance from the mesial of the first permanent molar to the calculated 'after alignment' position of the distal corner of the lateral incisor (Figure 2).

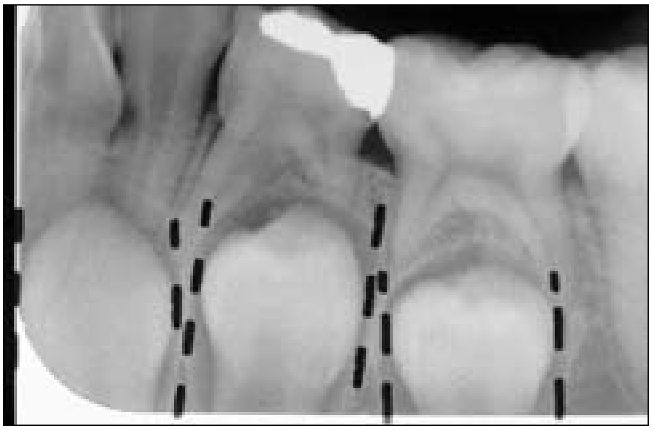

Figure 3 Measurement of apparent widths of canine and premolars

Estimation of the size of the unerupted teeth can be carried out using three basic approaches suggested by Proffit and Ackerman [1] namely: (1) measurement of the teeth on radiograph; (2) estimation from proportionality tables; and (3) combining data from radiographs and prediction tables.

The radiographic method requires an undistorted image in order to obtain accurate estimations [11]. Compensation for any enlargement of the radiographic image involves measuring an object that can be seen on the radiograph (apparent width) and on the study casts (true width), using a simple proportional relationship setup (Figure 3):

$$\frac{\text{True width of primary molar}}{\text{Apparent width of primary molar}} = \frac{\text{True width of unerupted premolar}}{\text{Apparent width of unerupted premolar}}$$

The accuracy of the method is fair to good, depending on the quality of the radiographs and the position of the teeth in the arch. It can be used for the upper and lower arch in all ethnic groups, but obtaining an undistorted view of the canines is usually difficult.

The Moyers prediction table [3] is one of the well-known methods for predicting the size of unerupted teeth; the lower incisors width measurements are used to estimate the size of maxillary and mandibular unerupted canines and premolars. Tanaka and Johnston [12] developed an alternative means based on the formula:

$$0.5 \times (\text{Mesiodistal width of four lower incisors}) + x\text{ mm} = \text{Estimated mesiodistal width of canine and premolars per quadrant}$$

(where x=10.5 for the mandibular arch and 11.0 for the maxillary archs)

The Moyers [3] as well as the Tanaka and Johnston [12] predictions were both based on white children of northern European descent. For Southern Chinese, the Tanaka and Johnston [12] method needs some adjustments, due to tooth size difference between ethnic groups as well as between the Southern Chinese males and females [13]. The authors recommended that for males, the x value should be 10.5 for the mandibular arch and 11.5 for the maxillary arch. Corresponding values for females were 10.0 and 11.0, respectively.

The combination method entails measurements from the study casts and width measurements from the periapical radiograph, in order to further improve prediction accuracy. The sizes of the permanent incisors measured from the dental casts and that of the unerupted premolar from the periapical X-rays are used to predict the size of unerupted canines. Staley and Kerber [14] modified the Hixon and Oldfather [15] method, to develop a prediction graph using the Iowa growth data, which allows canine width to be read off directly from the graph. This prediction graph provides the relationship between the size of lower incisors measured from study casts plus the first and second premolars measured from radiographs (x-axis) and the size of the canine plus premolars (y-axis). The Staley and Kerber [14] method was based on Caucasian children of northern European descent. Moreover, this method is only applicable to the mandibular arch.

To conclude, for Caucasian children, the Hixon and Oldfather [15] method gives the best prediction followed by the methods described by Tanaka and Johnston [12] as well as by Moyers [3]. The Tanaka and Johnston [12] approach is the most practical, since no radiographs are required and for the Chinese, the modified Tanaka and Johnston [12] approach is the most practical. For other ethnic groups, direct measurement from the radiographs is the best approach.

Tooth size discrepancies

Comparing tooth size, available space and identification of disharmonies of tooth size within the dental arch has a great impact during orthodontic diagnosis and treatment planning, as space management is very important. For a good occlusion, the dentition needs to be proportionately sized.

The Bolton Analysis is named after its inventor [16] and is very frequently used in the field of orthodontics to detect tooth size discrepancy. The analysis determines the ratio of the mesiodistal widths of maxillary versus mandibular teeth. It helps to estimate the overbite and overjet relationship, that will likely be obtained after orthodontic treatment is complete and the occlusal misfits produced by interarch tooth size discrepancy are identified [3]. The overall ratio determines the relationship between the 12 mandibular and 12 maxillary teeth (after excluding the second and third molars); the anterior ratio is between the six upper and lower anteriors.

The procedure is as follows: the sum of the widths of the 12 mandibular teeth is divided by the sum of the 12 maxillary teeth and multiplied by 100. A mean ratio of 91.3, according to Bolton, will result in ideal overbite-overjet relationships, as well as posterior occlusion. If the overall ratio exceeds 91.3, the discrepancy is due to excessive mandibular tooth material and vice versa. A similar ratio (anterior ratio) is computed for the six anterior teeth (incisors and cuspids). An anterior ratio of 77.2 provides ideal overbite and overjet relationships, so long as the angulation of the incisors is correct and the labiolingual thickness of the incisal edges is not excessive. If the overall ratio exceeds 77.2, the discrepancy is due to excessive mandibular tooth material and vice versa.

A tooth size discrepancy of less than 1.5 mm is relatively insignificant [1] but larger discrepancies (e.g. > ±2 SD) create treatment problems [17]. In a Chinese sample, it was reported that the Bolton standards applied to Southern Chinese children with Class I occlusion, but not to those with Class II or Class III occlusions for whom specific standards need to be established [18].

Dental archform

Assessment of dental archform is an important aspect of orthodontics because depending on conditions, some archforms have to be altered while others need preserving. The dental archform can be defined as the position and relationship the teeth have to each other [19]. Felton *et al* [20] reported that as there is great individual variability in archform, in many cases customizing the individual archform appears necessary to obtain optimum long-term stability. According to de la Cruz *et al* [21],

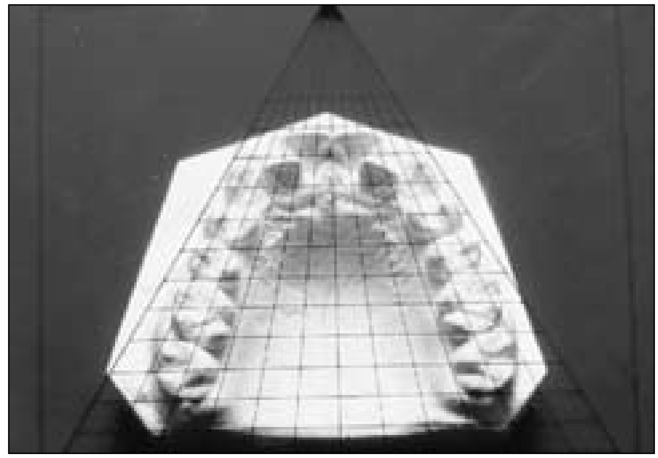

Figure 4 Grid to check archform and symmetry

archform tended to return toward the pretreatment shape after retention and suggested that the patient's pretreatment archform be used as a guide for future archform stability.

Asymmetry within the dental arch can result from lateral drift of incisors or drift of posterior teeth. Lateral drift of incisors occurs frequently in patients with severe crowding, particularly if the primary canines are lost prematurely. Posterior drift is usually caused by early loss of primary molar teeth [1]. The features of mesially drifted posterior teeth could be: (1) crowding and space loss; (2) dental midline shift with crowding and space loss; (3) mesial tipping of permanent molars; or (4) rotation of permanent molars [10]. A grid can be used to check the symmetry and form of the dental arch (Figure 4).

The curve of Spee

The curve of Spee is defined as the anatomic curve established by the occlusal alignment of the teeth, as projected onto the median plane, beginning with the cusp tip of the mandibular canine and following the buccal cusp tips of the premolar and molar teeth [22]. The curve of Spee is measured by determining the furthest perpendicular distance from a line connecting the second molar and the central incisor. The importance of this curve in orthodontic planning is that it requires space to become level without proclining the incisors (Figure 5). Thus, a 3-mm deep curve of Spee requires 3 mm of space for leveling (1.5 mm for each lower quadrant) [23].

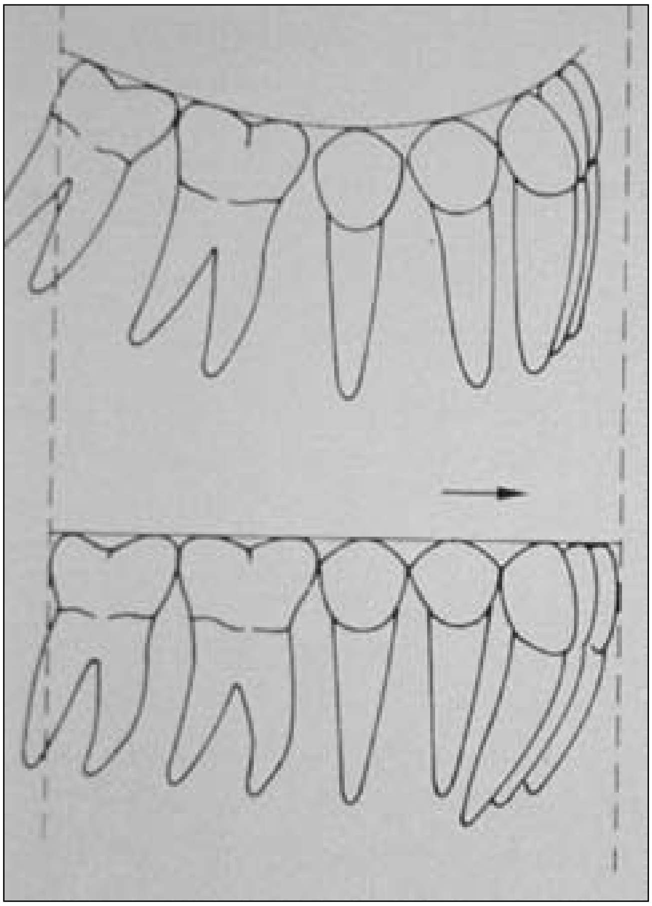

Figure 5 Space required for leveling curve of Spee

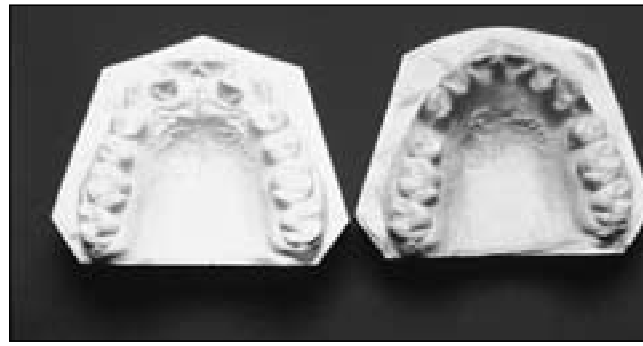

Figure 6 Diagnostic setup

Other investigations (related to space analyses)

Diagnostic setup

The diagnostic setup helps clinicians ascertain the precise amount of tooth movement and direction of movement, before orthodontic treatment [3]. By this means, space problems in the permanent dentition can be used to visualize in three dimensions, by cutting off the teeth from a set of casts and resetting them in more desirable positions (Figure 6). When extractions are contemplated as part of the orthodontic treatment for tooth size discrepancies or missing teeth, the diagnostic setup will vividly demonstrate the amount of space created by the extractions, and the tooth movements necessary to close the space. It will also aid in choosing which teeth to extract. It is also useful in multidisciplinary cases where crown modification, extractions, or prosthesis/implants are needed. Based on the setup, the orthodontist will know how much to move each individual tooth and the restorative dentist will know to what extent the teeth should be reshaped and how prostheses/implants should be placed.

Howes' Analysis

Howes' Analysis was devised to help clinicians determine whether apical bases could accommodate patient's teeth and in cases with suspected apical bases deficiency decide whether to extract teeth, or carry out dental or palatal expansions [24,25]. Howes believed that the premolar basal arch width should equal approximately 44% of the mesiodistal widths of the 12 teeth in the maxilla, if it was to be sufficient to accommodate all the teeth. When the ratio between basal arch width and tooth material is less than 37%, Howes considered this to be a basal arch deficiency, necessitating extraction of premolars. If the premolar basal width was greater than the premolar coronal arch width, expansion of the premolars may be undertaken safely. Details of the technique are summarized in Moyer's standard text [3].

The Royal London Space Planning

The Royal London Space Planning process has evolved since 1985 to ensure a disciplined approach to diagnosis and treatment planning and to provide a record to justify treatment decisions for professional accountability [9,26]. The analysis takes into consideration most aspects of a given malocclusion and aims to quantify the space required in each dental arch to attain the treatment objectives. This space planning also helps determine whether the objectives are likely to be attainable and helps in the planning of treatment mechanics and the control of anchorage.

The process of analysis is divided into two sections. The first part entails assessing the original malocclusion according to various components (which includes crowding and spacing, occlusal curves, arch width, anteroposterior position of labial segments, mesiodistal angulation, and incisor inclination). Any one of these can have an effect on space, if altered during treatment. The second part of the analysis, deals with the effect of treatment procedures (extractions, tooth size modifications, distal or mesial molar movements) as well as natural growth on the space required. The entire procedure has been comprehensively described in the original literature [9,26].

To assess and record the jaw relationship

This three-dimensional (3D) analysis estimates the intermaxillary relationship between the upper and lower dental arches in anteroposterior, transverse, and vertical dimensions [10]. For the anteroposterior relationship, the overjet (increased/reduced) and the molar/canine relationships (e.g. angle classification) can be assessed. For the anteroposterior assessment, the molar relationship will affect the decision as to whether the molars need distal or mesial movement and the anchorage demand can also be assessed.

The transverse analysis using the midsagittal plane as the reference, can be used to evaluate maxillary and mandibular midlines coincidence, transverse symmetry of the arches and interarch transverse relationships which can be normal, crossbite or scissor bites [11]. The transverse assessment also provides information about the width of the dental arch and the position of the teeth on the alveolar ridge. Expansions in the cases where the posterior teeth are tilted lingually/palatally tend to be stable, as the expansion is mainly by tilting the teeth buccally. Arch expansion is indicated for cases with unilateral crossbite, to eliminate displacement as well as the "V"-shaped archform as in the thumb-sucker [27,28].

The vertical analysis involves assessing the overbite condition, which can be deep, open or incomplete. Vertical assessment especially in the deep bite situation, is much more accurate when using the study cast than by clinical examination, as it is possible to view the intercuspation from the posterior aspect of the study casts [29]. In addition to the study models, the vertical dimension also needs the appropriate radiographs (e.g. lateral cephalometric radiograph) to make a sensible diagnosis.

The use of articulators

To aid diagnosis and treatment planning of orthodontics several authors have advocated the use of articulated study casts [30,31]. According to Proffit and Ackerman [1], the two main reasons to mount the study casts are: (1) to record and document any discrepancy between the occlusal relations at the initial tooth contact (centric relation) as well as the relations at the patient's habitual occlusion (centric occlusion), and (2) to record the lateral and excursive paths of the mandible.

A recent study reported that routine articulation of study casts for all orthodontic patients is not advocated and will not affect the treatment planning decisions compared with hand-held study casts [32]. Another use of articulators is for planning of combined surgical orthodontics cases.

Model (analysis) surgery—for combined surgical orthodontic cases

The study casts are very useful in dealing with various aspects of orthognathic and distraction osteogenesis [33,34]. Arnett and McLaughlin [35] recommended that three areas of model analysis need to be accomplished: (1) indication for orthodontic extraction, (2) orthodontic stability, and (3) surgical decisions. Furthermore, presurgical study casts are needed for model planning and interocclusal splint fabrication [36].

The object of model planning is to determine the intended occlusion and archform, and to decide the exact amount and direction of movement of the arches or segments thereof. Both must be undertaken at the same time as the photographic, cephalometric, and computer simulation studies [37].

Other information—on soft and hard tissues

Important information about the soft and hard tissues can be gathered from the study casts, including: gingival contour, gingival recession, crown height, bony exostosis, unerupted teeth (possibly shown as bulging areas), and areas of thin cortical plate where the root outline can be visualized. From the frontal view, the apparent sizes of teeth should become progressively smaller from the midline distally; the approximate golden ratio being 0.618 [38]. Thus, starting at the midline, this geometric formula of proportionality predicts that the width for each of the anterior teeth should be around 60% of the apparent width of the tooth immediately mesial to it.

The palatal height of the upper arch is measured along a virtual vertical line perpendicular to the midpalatal raphe. A high palatal vault is a principal feature of narrowing of the maxillary alveolar process, which often occurs in patients who are chronic mouth-breathers or digit suckers [10]. On the other hand, the presence of bony exostosis can hinder the treatment and retention with removable appliances.

Limitations of study casts

It is not possible to assess structures that are located in the bone such as unerupted teeth with study casts. As a general rule, if a permanent tooth on one side erupts but its counterpart on the other fails to do so within 6 months, an X-ray should be taken to investigate the cause of the problem [39]. Furthermore, it does not provide information about the extraoral soft tissue. Therefore, a well-treated orthodontic case evidenced on study casts may not necessarily produce an esthetic smile [2]. The smile line and lip prominence are very important, as both features will affect orthodontic treatment modalities/ options [1]. Certain features of the smile are crucial for orthodontics diagnosis and treatment planning. The transverse characteristics of a smile depend on: (1) buccal corridor width, (2) archforms, (3) the transverse cant of the maxillary occlusal plane. The vertical characteristics of a smile depend on: (1) incisor exposure and (2) gingival display, both of which are not normally obtainable from study casts [2].

e-Models

As we move into the 21st century there have been many advances in dentistry, particularly with respect to digital imaging. Digital study models can be produced by computed tomographic scanning of a patient's dental impression or dental cast [40]. This process requires silicone or polyether impressions to be taken in the orthodontic office. Instead of being poured by the orthodontist, impressions are shipped overnight to one of the companies offering digital models. A traditional plaster model is then fabricated and, using computer aided design and manufacturing (CAD/CAM) technology, it is transformed into a digital, 3D image of the dentition. Within a few days, a downloadable electronic file is available from the Internet. Once downloaded, software enables the digital models to be viewed and manipulated [41]. This technique has been used for the diagnosis, treatment planning, and fabrication of orthodontic appliance such as the Invisalign (Align Technology, Santa Clara, California, US) [40], which has also been approved by the Dental Council of Hong Kong as a means for orthodontic recording.

Advantages include reduction in space needed to store the models, easy retrieval and transmission. In addition, they will not be affected by dust and scratches anymore. Measurement on the dental cast (such as space analysis) can be carried out on the digital model without the cumbersome use of caliper [42]. The digitized models can be viewed from any angle and also opened to allow upper and lower models to be viewed separately. They can also be turned back into genuine set of study models if needed [43]. Another advantage is the possibility of viewing digital models at multiple locations from any office computer linked to the practice's central server, allowing patients to be treated at multiple sites with easy access to their records. Furthermore, digital models are also an excellent presentation and patient education tool. Thus, the digital models available today offer seamless integration into most of computerized practice management and imaging systems and are part of the totally digital orthodontic office [41].

For OrthoCAD (Cadent Inc., New Jersey, US), alginate impressions of the dentitions with bite registration are required for construction of 3D digital study models, which are then downloaded manually or automatically from the Internet using a utility called OrthoCAD Downloader. One feature of Ortho-CAD facilitates viewing of interocclusal contacts, which cannot be easily done in physical models. Another feature, OrthoCAD Bracket Placement System enables positioning brackets according to orthodontists' planned positions in virtual treatment.

The other computerized model system is called e-models (GeoDigm Corporation, US). It features a cross-sectioning tool that can slice the digital models in any vertical or horizontal plane to check symmetry, overjet, and overbite and to help measure any location. There is a Color Bite Mapping feature that is a visual representation of occlusal relationships. *E*plan (GeoDigm Corporation, US) is the other useful feature of this e-model's software. The latter feature enables the clinician to simulate any desired treatment option by using a virtual diagnostic setup [41].

There are some potential limitations about digital models, however. First, one must learn to analyze study casts on a computer screen. It is possible to view the casts from a myriad of angles, but comfortable manipulation takes some practice. Second, large practices must ensure plenty of available computer memory. Third, to date it is not possible to relate the casts to the hinge axis. Fourth, it cannot be placed side by side to the teeth for comparison.

Conclusions

Study casts provide valuable information for orthodontic diagnosis and treatment planning. Full utilization of such information requires special attention and techniques. They are important medico-legal documents that should be obtained before commencement of every orthodontic treatment. It is possible to be alleged negligent for not having starting and finishing study models.

References

1. Proffit WR, Ackerman JL. Orthodontics diagnosis: the development of a problem list. In: Proffitt WR, Fields HW, editors. Contemporary orthodontics. 3rd ed. St. Louis: Mosby; 2000: 147-95.
2. Sarver DM, Proffit WR. Special considerations in diagnosis and treatment planning. In: Graber TM, Vanarsdall RL, Vig KW, editors. Orthodontics: current principles & techniques. 4th ed. St. Louis: Elsevier Mosby; 2005:3-70.
3. Moyers RE. Analysis of the dentition and occlusion. In: Moyers RE, editor. Handbook of orthodontics. 4th ed. Chicago: Year Book Medical Publishers; 1988:221-46.
4. Bjork A, Krebs A, Solow B. A method for epidemiological registration of malocclusion. Acta Odont Scand 1964;22:391-9.
5. Tsai SJ, King NM. A catalogue of anomalies and traits of the permanent dentition of southern Chinese. J Clin Pediatr Dent 1998;22:185-94.
6. Bedi R, Pitts NB. Dens evaginatus in the Hong Kong Chinese population. Endod Dent Traumatol 1988;4:104-7.
7. Sim TP. Management of dens evaginatus: evaluation of two prophylactic treatment methods. Endod Dent Traumatol 1996; 12:137-40.
8. Chu FC, Sham AS, Yip KH. Fractured dens evaginatus and unusual periapical radiolucency. Dent Traumatol 2002;18:339-41.
9. Kirschen RH, O'higgins EA, Lee RT. The Royal London Space Planning: an integration of space analysis and treatment planning: Part I: Assessing the space required to meet treatment objectives. Am J Orthod Dentofacial Orthop 2000;118:448-55.
10. Nance HN. The limitations of orthodontic treatment. I. Mixed dentition diagnosis and treatment. American Journal of Orthodontics and Oral Surgery 1947;33:177-223.
11. Gregoret J, Tuber E, Escobar PL, da Fonseca AM. Oral evaluation. In: Gregoret J, Tuber E, Escobar PL, da Fonseca AM, editors. Orthodontics and orthognathic surgery diagnosis and planning. Barcelona: Publicaciones Medicas; 2003:31-73.
12. Tanaka MM, Johnston LE. The prediction of the size of unerupted canines and premolars in a contemporary orthodontic population. J Am Dent Assoc 1974;88:798-801.
13. Ling JY, Wong RW. Tanaka-johnston mixed dentition analysis for southern Chinese in Hong Kong. Angle Orthod 2006;76:632-6.
14. Staley RN, Kerber PE. A revision of the Hixon and Oldfather mixed-dentition prediction method. Am J Orthod 1980;78:296-302.
15. Hixon EH, Oldfather RE. Estimation of the sizes of unerupted cuspid and bicuspid teeth. Angle Orthod 1958;28:236-40.
16. Bolton WA. The clinical application of tooth-size analysis. Am J Orthod 1962;48:504-29.
17. Freeman JE, Maskeroni AJ, Lorton L. Frequency of Bolton tooth-size discrepancies among orthodontic patients. Am J Orthod Dentofacial Orthop 1996;110:24-7.
18. Ta TA, Ling JY, Hagg U. Tooth-size discrepancies among different occlusion groups of southern Chinese children. Am J Orthod Dentofacial Orthop 2001;120:556-8.
19. Attack N, Turner S, Thomas P, Nattrass C, Sandy JR. Postgraduate notes in orthodontics MSc/MOrth programme. 2nd ed. Division of Child Dental Health, Bristol Dental School, University of Bristol; 2000:42-3.
20. Felton JM, Sinclair PM, Jones DL, Alexander RG. A computerized analysis of the shape and stability of mandibular arch form. Am J Orthod Dentofacial Orthop 1987;92:478-83.
21. de la Cruz A, Sampson P, Little RM, Artun J, Shapiro PA. Long-term changes in arch form after orthodontic treatment and retention. Am J Orthod Dentofacial Orthop 1995;107:518-30.
22. The glossary of prosthodontic terms. J Prosthet Dent 2005;94:10-92.
23. Bennett JC, McLaughlin RP. Management of the dentition. In: Bennett JC, McLaughlin RP, editors. Orthodontic management of the dentition with the preadjusted appliance. Oxford: Mosby; 1997:1-24.
24. Howes AE. A polygon portrayal of coronal and basal arch dimensions in the horizontal plane. Am J Orthod 1954;40:811.
25. Howes AE. Expansion as a treatment procedure—where does it stand today? Am J Orthod 1960;46:515.
26. Kirschen RH, O'Higgins EA, Lee RT. The Royal London Space Planning: an integration of space analysis and treatment planning: Part II: the effect of other treatment procedures on space. Am J Orthod Dentofacial Orthop 2000;118:456-61.
27. Bell RA, LeCompte EJ. The effects of maxillary expansion using a quad-helix appliance during the deciduous and mixed dentitions. Am J Orthod 1981;79:152-61.
28. McNamara JA, Brudon WL. Treatment of tooth-size/arch-size discrepancy problems. In: McNamara JA, Brudon WL, editors. Orthodontic and orthopaedic treatment in the mixed dentition. Ann Arbor: Needham Press; 1993:67-93.
29. McDonald F, Ireland AJ. Orthodontics records and diagnostic test. In: McDonald F, Ireland AJ, editors. Diagnosis of the orthodontic patient. Oxford: Oxford University Press; 1998:149-76.
30. Cordray FE. Centric relation treatment and articulator mountings in orthodontics. Angle Orthod 1996;66:153-8.
31. Roth RH. Functional occlusion for the orthodontist. J Clin Orthod 1981;15:32-40, 44-51 contd.
32. Ellis PE, Benson PE. Does articulating study casts make a difference to treatment planning? J Orthod 2003;30:45-9.
33. Musich DR. Orthodontic aspects of orthognathic surgery. In: Graber TM, Vanarsdall RL, Vig KW, editors. Orthodontics: current principles and techniques. 4th ed. St. Louis: Elsevier Mosby; 2005:993-1052.

34. Cope BC, Samchukov ML. Craniofacial distraction osteogenesis: basic principles and clinical applications. In: Graber TM, Vanarsdall RL, Vig KW, editors. Orthodontics: current principles and techniques. 4th ed. St. Louis: Elsevier Mosby; 2005:1053-96.
35. Arnett GW, McLaughlin RP. Facial and dental planning for orthodontists and oral surgeons. Edinburgh: Mosby; 2004:183-4.
36. Bailey LT, Proffit WR. Combined surgical and orthodontic treatment. In: Proffit WR, Fields HW, editors. Contemporary orthodontics. 3rd ed. St. Louis: Mosby; 2000:674-709.
37. Henderson D. Model planning. In: Henderson D. A colour atlas and textbook of orthognathic surgery. London: Wolfe; 1985:83-90.
38. Shillingburg HT, Hobo S, Whitsett LD, Jacobi R, Brackett SE. Esthetics considerations. In: Shillingburg HT, Hobo S, Whitsett LD, Jacobi R, Brackett SE, editors. Fundamentals of fixed prosthodontics, 3rd ed. Chicago: Quintessence Publishing Co. Ltd.; 1997:419-31.
39. Proffit WR, Fields HW. Early stages of development. In: Proffit WR, Fields HW, editors. Contemporary orthodontics. 3rd ed. St. Louis: Mosby; 2000:63-93.
40. Mah JK, Hatcher D. Craniofacial imaging in orthodontics. In Graber TM, Vanarsdall RL, Vig KW, editors. Orthodontics: current principles and techniques. 4th ed. St. Louis: Elsevier Mosby; 2005:71-100.
41. Isaacson RJ. e-Models: a new digital orthodontic record. In: Takada K, Proffit WR, editors. Orthodontics in 21st century. Where are we now? Where are we going? Osaka: University Press; 2002:69-74.
42. Peluso MJ, Josell SD, Levine SW, Lorei BJ. Digital models: an introduction. Seminars in Orthodontics 2004;10:226-38.
43. Sandler PJ, Murray AM, Bearn D. Digital records in orthodontics. Dent Update 2002;29:18-24.