Clinical and scientific applications/advances in video imaging

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For many of us, the coming of the computer age has been a painful, sometimes frustrating experience. We have had to learn a whole new vocabulary. We have had to make expensive decisions, often with information that we didn't quite understand. Do I really need hardware with this much power? Will this software do what they say it will? Will the choices I make today still work tomorrow? It felt, at times, like trying to sail a boat without navigational equipment.

We believe our patients often feel the same way when they try to navigate their way through our explanations of the care they are going to receive and what the predicted outcome might be. This is why the computer, particularly video imaging, is so right for our time.

Historical perspective of growth and treatment predictability

Predictability is no stranger to orthodontists. Researchers and clinicians alike have been struggling with the subject for years in an attempt to facilitate treatment and inform patients of possible outcomes. Growth and development forecasts generally fall into three categories: (1) longitudinal history, using serial cephalometric superimpositions; (2) individual variations, such as genetics or facial and skeletal morphology, and internal geometric arrangements as depicted on single headfilms; or (3) statistical information developed on average growth measurements (increments) according to the age and sex of the patient.

Today, these three elements can be combined, using computers to facilitate the prediction.

Longitudinal history

The longitudinal history method requires observation of growth over a long period of time. The findings of Broadbent[1] and Brodie[2] suggested an orderliness to the pattern of facial growth. Tweed,[3] Graber,[4] and others also used serial headfilms and assumed future growth

Abstract

This paper discusses the current capabilities and limitations of video imaging. Probable future applications are suggested, including the use of video imaging as an adjunct for esthetic diagnosis and treatment planning and as a means of providing realistic representations to patients of probable treatment outcomes. The widespread use of video imaging to facilitate interactive informed consent and rapid interspecialty communication and transfer of data is predicted and discussed.

Key Words

Video imaging • Morphing • Esthetics • Communication, interspecialty • Informed consent

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Figure 1

Figure 1 Consultaion using video imaging helps eliminate misconceptions.

would follow trends established by analysis of growth over a few years. More recent evidence suggests growth patterns may be nonlinear.[5-7]

Individual variation

Studies[8] have shown that a more precise forecast of an individual's growth could be made by applying specific hereditary factors to the cephalometric prediction. Nakata[9] reported that anterior cranial base morphology was strongly influenced by genetic factors, and Arya[10] studied the influence of genetic factors on mandibular length. Nakasima and Ichinose[11] studied the role of parental variables in predicting facial growth after treatment of anterior crossbites and concluded that for any prediction system to have validity it needed comparative dimensions between parents and their offspring. Houston and Brown[12] indicated that although a number of craniofacial features are under polygenic control, family resemblance does not offer a sound basis for the prediction of facial growth in the individual child.

Other attempts at growth prediction have centered on the evaluation of certain characteristics of the craniofacial complex. Some investigators have suggested that an increased mandibular plane angle is associated with a backward rotational growth pattern.[13,14] However, Baumrind et al.[15] and Skieller and Björk[16] agreed that a high mandibular plane angle alone is not a good predictor of facial growth because it may be present in people who exhibit either backward or forward mandibular growth. Other studies have focused on the gonial angle as a predictor of vertical growth. Björk concluded that gonial angle was statistically invalid as a predictor of growth patterns for individuals.

Björk's implant studies described multiple structural signs in extreme types of mandibular rotators. According to his research, forward mandibular rotators are associated with a forward inclination of the condylar head and a greater curvature of the mandibular canal as compared with the mandibular contour, while the tendency toward backward mandibular rotation seems to be closely allied to a pronounced apposition below the symphysis with more overall resorption and concavity of the lower mandibular border.[17-21]

Singer and Mamandras[22] suggested that the presence of a deep mandibular antegonial notch is indicative of diminished mandibular growth potential. Aki and Nanda[23] assessed symphysis morphology as a predictor of the direction of mandibular growth, and their results were consistent with Björk's findings. Some investigators have focused their attention on other parts of the craniofacial complex. Solow[24] presented evidence for a relationship between craniocervical posture in prepubertal children and the direction of facial development during the subsequent period of growth.

Although many cephalometric measurements have been used in predicting the direction of mandibular growth, accurate forecasting remains unreliable. Baumrind, Korn, and West[25] conducted a study in which five "expert" clinicians, using standard methods, attempted to predict the direction of mandibular growth in 64 Class II mixed dentition subjects. The results clearly showed the inability of the clinicians to differentiate potential "forward rotators" from potential "backward rotators," and hence concluded that prediction of the direction of mandibular growth by lateral cephalometrics was very unreliable.

Statistical information

Adding average increments derived from a normative sample to the recorded actual facial dimensions of patients was first suggested by Hixon.[26] Similarly, Ricketts[27] introduced the arcial method of growth prediction using geometric procedures in which the accumulated past growth is projected to forecast further developments for a given patient. Johnston[28] developed a simplified method of generating long-term forecasts by the use of a printed "forecast grid," and Popovich[29] introduced "craniofacial templates," which are based on individual age, sex, and growth patterns.

Computer forecasting

Ricketts advocated the use of computers to predict growth because they could put large amounts of data into a clinically useful form. This led to the development of the original version of the Rocky Mountain Data Systems (RMDS). Greenberg and Johnston[30] evaluated the accuracy of commercial systems and reported that they were no more accurate than the use of constants derived from an independent sample. In a larger study, using refined computer methods that took into account individual facial patterns, Schulhof and Bagha[31] concluded that the computer forecasts were not markedly more accurate in the 70% of patients who were in the normal range, but they showed considerable advantage for the 30% with abnormal patterns, including vertical tendencies. More recently, Thames, Sinclair, and Alexander[32] tested the accuracy of RMDS in predicting growth and treatment outcomes in Class II high angle cases. Their results demonstrated that 15 of the 30 parameters evaluated showed statistically significant differences between the actual posttreatment result and the prediction. In addition, soft tissue profile, which is one of the most critical areas of interest in the evaluation of a treatment plan, was found to be one of the weakest aspects of the system. In 1992, Christie[33] announced his new growth forecasting computer program, Facial Print, which he claimed would allow practitioners to "see into the future." He compared a profile to a fingerprint. In his forecast, an individual's growth predictions are based on ethnicity, sex, skeletal age, and facial pattern. According to Rocky Mountain Orthodontics, regarding the sampling of more than 3564 cases, Christie's forecast predicted the location and size of the mandible to a deviation of 0.16 mm per skeletal year.

Today, video imaging programs incorporate growth forecasting in their diagnostic armamentaria. In his thesis, DiCiccio[35] assessed the accuracy and reliability of the long-range growth predictions of three computer software systems (Quick Ceph for Apple Macintosh, Rocky Mountain Data Systems for IBM mainframe systems, and Facial Print for IBM personal computers) for untreated Class I individuals. When comparing the predicted growth with actual changes, he found no system was clearly more accurate or predictable than the others. Further, all systems predicted skeletal structure, x-coordinates, and maxillary points better than soft tissue structures, y-coordinates, and mandibular points, respectively.

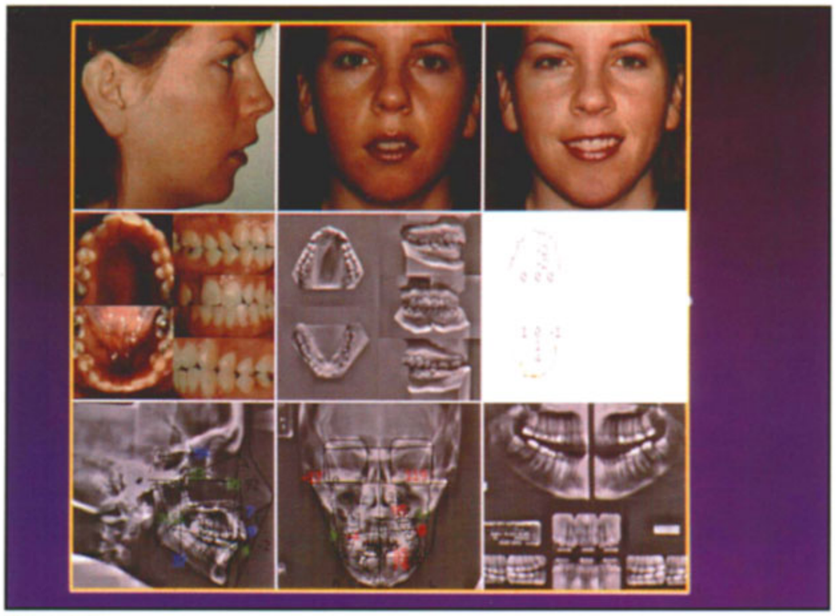

Figure 2

Figure 2
Interactive records display.

Where then does predictive computerized cephalometrics and video imaging find a place in the modern-day orthodontic practice, and what is the accuracy of this intriguing technology? Perhaps some of the answers will be forthcoming. But the present research indicates that the use of these tools as predictors for anything other than tooth movement and surgical skeletal change (static determinants) is probably unreliable.

Video imaging: Vibrant adjunct for esthetic diagnosis and communication?

Clearly, our society has changed greatly since orthodontics was accepted as a viable entity in the health care profession. Garber and Goldstein[35] reflect the awareness of this change: "The practice of dentistry is changing from a needs-based to a wants-based delivery of service, and computer imaging is a tool that invites and facilitates interactive communication."

In his commentary, Sarver[36] asks some very specific questions regarding the communication aspect of video imaging, focusing on patient interaction, predictive results versus actual findings, and implied guarantee. While he points out some compelling concerns regarding implied guarantees and their potential legal implications, later data suggest that improved communications and an interactive decisionmaking process with realistic expectations lessens these fears.

Ackerman and Proffit[37] suggest that orthodontic treatment planning is an interactive process in which the patient, parent, and orthodontist serve as co-decisionmakers. Each looks at the problem list from a different perspective, and

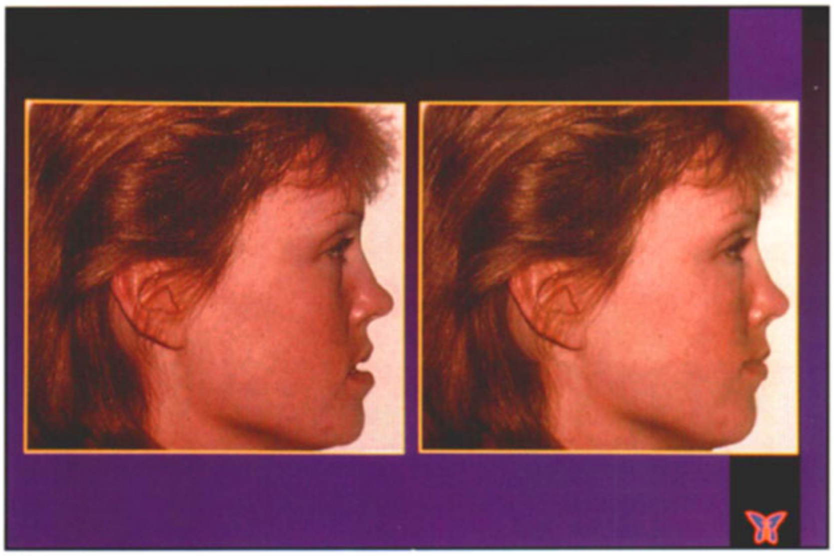

Figure 3

Figure 4

Figure 3
Realistic expectations of treatment.

Figure 4
Prediction versus actual surgical outcome.

video imaging can be a platform that enhances the patient's understanding. Eliminating misconceptions and allowing for full disclosure results in great benefits in the areas of risk management and bioethical practice.

Some of the other benefits of video imaging include: clearer communication with patients, better data manipulation, improved treatment planning, and enhanced interfacing with collaborating specialists. Let us the explore each of these specific areas more fully.

Improved communication

Patient understanding: When we inform a patient of our diagnostic findings and suggest a treatment plan to be followed, including possible alternatives to the primary course of care, full disclosure helps to create an environment of understanding and begins to build a bridge of confidence between the care provider and the patient or parents. In a recent editorial, Turpin[38] carefully crafted a scenario that describes the dilemma faced by everyone in our specialty: How do I offer, in an understandable way, the information necessary for the patient to visualize the results of orthognathic surgery or camouflage care before the fact? Video imaging, perhaps, is that medium. Using a computer or a TV screen—something with which everyone can identify—the clinician can simulate the probable treatment outcome and facilitate communication about the alternatives.

Realistic treatment expectations: Among the most compelling information to date is a study by Phillips, Hill, and Cannac[39] titled "The influence of video imaging on patients' perceptions and expectations." They found that the presentation of video images appears to be a valuable adjunct for conveying treatment options to patients, but caution may be needed to prevent elevated or possibly unrealistic treatment expectations. Further, video imaging was found to heighten patients' expectations of improvement in self image following treatment.

Patient acceptance: Ackerman and Proffit,[37] in their recent article "Communication in orthodontic treatment planning: bioethical and informed consent issues," suggest that with the advent of video imaging to forecast the outcome of care, the orthodontist has a powerful and reasonably accurate medium to compare and contrast for the patient the potential outcomes of various treatment alternatives. By substituting pictures for words, the practitioner can eliminate some of the misconceptions and doubts about what the final result will be. This type of visual dialogue imparts confidence and subsequently acceptance for the treatment recommendations.

Interactive informed consent: In the same article, Ackerman and Proffit[37] describe how, by changing their focus from an underlying hard tissue morphology to soft tissue relationship, orthodontists have initiated a departure from the practitioner being the sole decisionmaker in the treatment planning process. Bioethicists across the country and the jurisprudence system in many states have concluded that the doctor as the sole decisionmaker is paternalistic and an abuse of professional authority (Canterbury v. Spence 464F 2d 772 -D.C. Cir. 1972). Thus, it is now the doctor's legal as well as moral responsibility to fully advise the patient regarding risk/benefit considerations, treatment alternatives, compromise/camouflage care, or no treatment at all. This is the doctrine of informed consent, and video imaging helps the doctor and patient reach a successful, joint decision.

Data manipulation

Ease of archiving: Computer technology is developing at an explosive pace. Few of us have the time, money, or energy to integrate every improvement into our practice. Record storage and archiving will probably evolve into a primarily paperless system. Eventually each patient will have a file within a practice database that incorporates photographs, study casts, x-rays, tracings, and any other pertinent information necessary to develop a complete diagnosis and treatment plan.

Decreased storage space: Without image compression, an estimated 1.5 to 3.0 gigabytes of memory would be needed to fully record the data necessary for 400 patients and maintain contemporaneous records. This is an expensive process, but the cost of disk memory is decreasing rapidly. Alternatives to disk memory include, image compression and storage on optical or zip drives, which offer reasonable, reliable retrieval systems at an affordable cost. While the compression of images does cause some loss in clarity and accuracy, improvements in technology should soon correct this shortcoming.

Rapid comparison of treatment plans: Once the baseline data are entered and the practitioner becomes adept with a video imaging system, developing a surgical treatment plan may take only a few minutes. Testing alternative surgical plans becomes easy with a minimal investment of time. In a Class III case, for example, it may not be readily apparent whether maxillary advancement, mandibular set back, or some combination of the two, with or without genioplasty, is appropriate. With video imaging several treatment options can be worked up relatively quickly and the esthetic results easily compared. This significantly improves the confidence of the surgeon and others in the final treatment plan.

Improved treatment planning

Treatment planning from soft tissue analysis versus cephalometric data: Experienced clinicians have known intuitively for years that cephalometric analysis alone is a poor predictor of appropriate surgical treatment. Surgeons generally use cephalometric data for measurement of osseous movements only and do not rely on "the numbers" to choose which jaws to correct. Park and Burstone[40] demonstrated that treatment planning based on several cephalometric analyses resulted in very poor agreement between analyses, and no single analysis was reliable when planning orthognathic surgical care. Soft tissue esthetics has been the foundation of surgical treatment planning. The improvement of soft tissue visualization using video imaging has been a major advantage of this system in treatment planning. The surgeon's sense of esthetics and balance is complemented by the feedback available from the images on the computer screen.

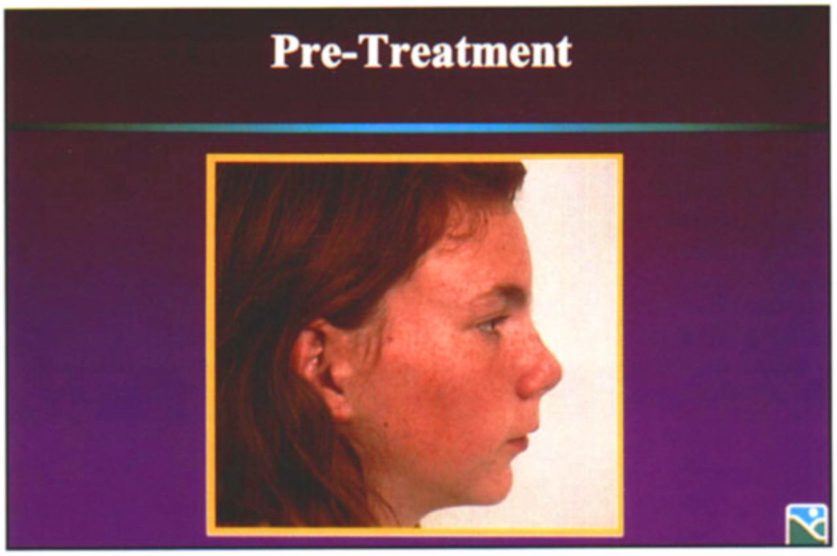

Figure 5A

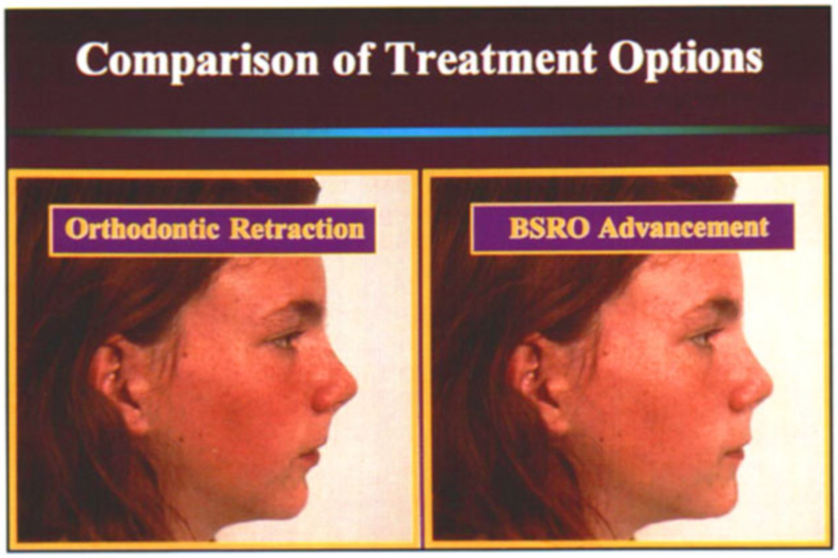

Figure 5B

Figure 5A-B
A. Patient pretreatment profile.
B. Predicted outcomes of two treatment options.

Immediate visualization with bony movements: The experienced clinician, using a high speed computer, improved computer algorithms, and video imaging software, can now reflect soft tissue changes within seconds of developing osseous changes during treatment planning sessions.

Rapid assimilation of various treatment possibilities: The ability to rapidly develop different treatment plans and then simultaneously project up to three of them on the screen helps the team compare options. Efficient, confident

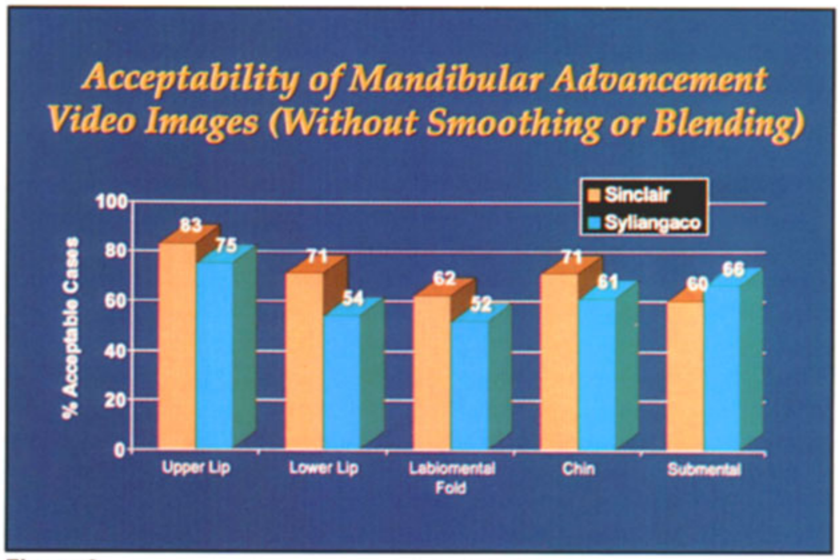

Figure 6

Figure 6
Graph showing accuracy of video imaging prediction with areas of anatomic interest.

decisions develop into final treatment strategies more easily with this technique.

Interface with collaborating specialists

Coordinated treatment planning: Collateral soft tissue esthetic surgery is rapidly evolving within the specialty of oral and maxillofacial surgery: facial liposuction, blepharoplasties, rhinoplasties, and rhytidectomies are becoming common. Many oral and maxillofacial surgeons who do not offer these procedures themselves work closely with plastic surgeons who do. At this time, video imaging has proved useful in limited areas of plastic surgery. Reflection of simple rhinoplasties and submental suction lipectomies can be accurately represented in video imaging, especially in the lateral view. Treatment planning and patient acceptance in these areas of adjunctive procedures is greatly enhanced when they are included in the video images. The more subtle changes seen with blepharoplasties, complex rhinoplasties with significant tip work, and rhytidectomies are difficult to accurately represent with present systems. Individuals with artistic talent and a comprehensive knowledge of "painting" with computers may be able to use imaging successfully in these areas. However, programs to automatically make these comparable to what is being done with orthognathic surgery are not yet available. Facial implants can be imaged in the chin area with the present systems. Zygomatic implants are more subtle. Again, only those experienced surgeons well versed in computer painting and who have artistic talent will find imaging representative and helpful.

Improved data exchange: While there are no research data to support the belief that improved communication occurs within the health care community using video imaging as an adjunct to diagnosis and treatment planning, common sense would dictate support for this concept. Practical experience indicates that communication and understanding are enhanced between professionals with the advent of video imaging as a tool for treatment planning

Historically, treatment planning on esthetic and orthognathic cases relied on cephalometric acetate tracings. This obviously left much to be desired in terms of subtle soft tissue changes. As a surgeon's skill and experience matured, he or she was able to infer a great deal from a simple line tracing. However, it was difficult, and often impossible, for the surgeon to convey what was in his or her mind to other members of the team. The addition of 3-D photos with video imaging has dramatically improved this communication. Certainly there are still many subtle soft tissue changes that predictive video imaging does not accurately reflect, but it is a significant improvement over acetate overlay tracings.

If all members of the treatment team have identical software, there is an additional advantage to video imaging. All members have access to the same high quality images on the screen. All surgical and orthodontic predictive changes can be viewed easily and can be reported in visual tabular formats. Using e-mail, it is now possible to send video image files to treatment collaborators, who can review the surgical plans, make changes as they seem indicated, and return the revised plans, literally within minutes. The improvement in data interchange and communication is a major difference from previous systems.

The accuracy of cephalometric and video imaging predictions

Cephalometric prediction accuracy assessment

The accuracy and reliability of digitized cephalometrics is an established fact. Richardson[41] and Houston[42] verified that digitized cephalometric tracings are at least as accurate as their manual counterparts. In a more recent study, Davis and Mackay[43] further supported the accuracy of interactive computer-assisted digitization. Electronic digitizing devices allow the mathematical calculation of angles and distances using Cartesian (x- and y-) coordinates from the digitized landmarks. Digitization can be accomplished on a cephalometric radiograph or a tracing of the radiograph. Now, digital radiography and computer imaging techniques can be combined with cephalometry, allowing a cephalometric image to be captured by a video camera, stored digitally, and retrieved for analysis when needed.

Friede et al.[44] tested the reliability of predicting results of orthodontic surgical treatment. His predictions showed great variation among the initial records, the prediction tracing, and subsequent final result. While there were significant disparities between the prediction and the treatment outcome, he offered explanations for the differences, suggested methods for improvement, and concluded that prediction tracings are still of value, despite their inaccuracy in some cases.

Nimkarn and Miles[45] suggested that despite a slight degree of distortion, the computerized cephalometric technique is still an extremely useful and accurate method of collecting cephalometric data for clinical purposes. The only variables in which there were statistically significant differences between the original and repeated measurements were in the vertical plane—primarily point B due to measurement error. The distortion error occurred on the right side of the screen, suggesting nonparallel placement of the video lens, recording surface, and/or the object being imaged.

If we assume that computer-generated cephalometrics is an accurate medium for clinical and research studies, what about its effectiveness as a measure for predictive growth, development, and orthodontic treatment? Thames, Sinclair, and Alexander[32] attempted to address this question in a study testing the accuracy of a commercially available forecasting system in predicting the effects of growth and treatment. Pretreatment cephalograms and wax bites of mandibular casts of 33 consecutively treated Class II patients with high mandibular plane angles and a number of other criteria related to treatment preference were submitted for analysis. The patients had already been treated on a nonextraction basis by one practitioner who used high pull headgear mechanics. The computer-generated posttreatment predictions or visual treatment objectives (VTOs) were compared with the actual posttreatment cephalograms using linear and angular measurements. One-half of the parameters evaluated showed statistically significant ($P<0.01$) differences between the actual posttreatment result and the computer prediction. The computer was found to be accurate in predicting the effects of growth and treatment on maxillary position and rotation, mandibular length, upper face height, and incisor position. It was found to be inaccurate in predicting the effects of growth and treatment on maxillary length, mandibular rotation, lower anterior and posterior face heights, the horizontal and vertical positions of the molars, and over 50% of the soft-tissue parameters.

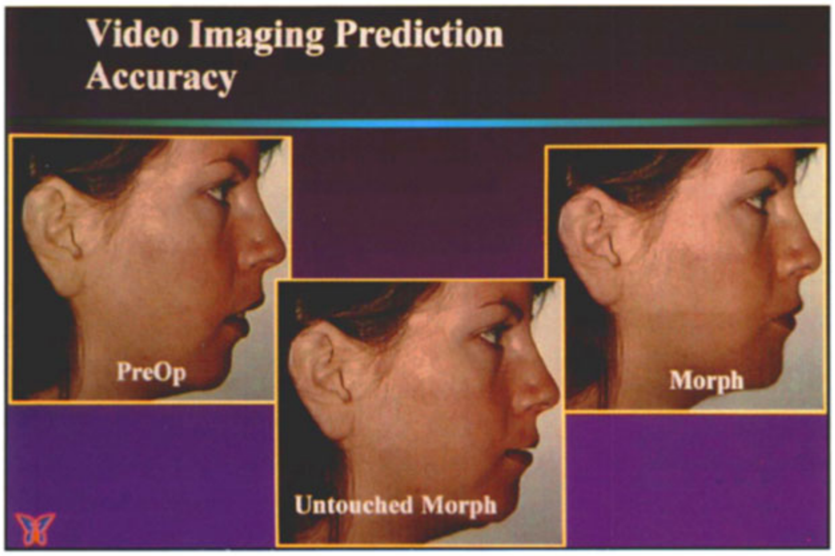

Figure 7

Figure 7
Prediction morph compared with touched up morph.

Assessing the accuracy of video imaging predictions

While it is imperative that communications with our patients be understandable and interactive, it is equally important that the information we disseminate be accurate. How reliable, then, are orthognathic surgical predictions using video imaging technology compared with the actual treatment results?

Visual treatment objective

The accuracy of video imaging predictions depends on three components. The first is the accuracy of the computerized cephalometric visual treatment objective (VTO). Researchers have evaluated the accuracy of these "line drawing predictions." Hing et al.,[46] Konstantinous, O'Reilly, and Close,[47] Eales,[48] and Upton[49] have shown that video imaging, whether IBM-, Macintosh-, or UNIX-based, is reasonably accurate in the anteroposterior plane when compared with manual prediction tracings, and slightly poorer but still acceptable in the vertical plane. All the software programs tested, however, had problems predicting the position of the lips, particularly the detailed morphology of the lower lip. These problems can be attributed to the paucity of data in the literature and also to the lip's variable response to orthognathic surgical procedures.

Fitting the facial image onto the cephalometric outline

The second element of video imaging accuracy lies in the ability of the program to fit the facial image onto the corresponding soft tissue cephalometric outline. All programs approach this task differently. Some provide great accuracy but at the expense of requiring considerable technical skill; others provide a more automated approach matching the profile and contours but give up a certain degree of accuracy in the process. The optimal system for the task has yet to be developed.

Morphing the image

The final leg of the video imaging triad is the computer software that predicts facial change by morphing the image to correspond to the underlying cephalometric profile while at the same time blending and smoothing the contours of the lips and chin. Recent research reports by Sinclair et al.,[50] Syliangco,[51] and Kawakami[52] have shown that for both mandibular advancement and maxillary impaction, approximately 70% of the video images produced can be considered accurate enough for clinical use in patient education as well as diagnosis and treatment planning. These images can be produced without any additional operator influence in blending or smoothing the profiles.

The area of greatest concern, where fewer than half the images show acceptable accuracy, again lies in predicting the contour and position of the lower lip. This area often requires additional attention by the operator to provide an acceptable image.

Summary and conclusions

The emergence of video imaging in the field of orthodontics represents the blending of several trends in orthodontic diagnosis and treatment planning.

1. It is the logical conclusion to the development of visual treatment objectives (VTOs) and provides the most realistic representation to date of a patient's probable treatment outcome.

2. It provides a means to address what is, for many patients, the chief concern—the esthetic appearance of the face and teeth—thereby facilitating the decision to proceed with or forego treatment.

3. It provides the orthodontist and the oral and maxillofacial surgeon with the most accurate means by which to rapidly evaluate different treatment alternatives and make the most appropriate treatment planning decisions.

4. It facilitates communication between different professional specialties as well as between professionals and patients and helps ensure that all expectations are addressed and that there is full consent and agreement as to the goals of treatment.

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