FORUM

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Taking stock: a critical perspective on contemporary orthodontics

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This essay briefly considers some underlying concerns about the direction of clinical research in orthodontics. The field is viewed from a personal perspective as things are now, as they are becoming, and as I believe they should be.

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Preface

Orthodontics is a complex process. It involves physical intervention in a continually changing system of great structural complexity – the human head. As the part of the organism that precedes the rest in the physical exploration of new environments, the head is necessarily complex. It is called upon to package a great number of sensors in a limited amount of space. Indeed the human head as it exists today can be viewed phylogenetically as the survivor of an evolutionary competition for a limited amount of space. It seems at times that the competition among sensory organs for space in the developing head is almost as fierce as the competition for office and laboratory space in many universities!

One of the most important biological functions of the human head, and particularly of the human face, is the need to be 'attractive'. Facial attractiveness has biological importance in 'the mating game', and psychosocial importance in each human individual's quest for social, political and economic advantage. The precise reason why 'facial attractiveness' has become such an important factor in the human choice of companions is unknown, or is at least beyond the scope of the present inquiry. Instead, the orthodontic specialty accepts the importance of 'facial attractiveness' as a given, and as a given it has become the cornerstone of contemporary orthodontics.

Yet although we focus on the face, we must remember that the face is part of a continuum and that the total region of orthodontic interest is quite a bit larger. It includes not only the whole of the patient's head, or even the whole of the physical patient, but rather the whole patient in interaction with the whole psychosocial milieu in which both patient and the therapist are embedded. Given our available resources, that system is much too large to be more than noted, so we choose most of the time to limit our scope to the study of craniofacial 'morphology'.

But even in this more limited region of interest, we are faced with greater complexity than we can readily manage, because the face and the stomatognathic system are not static during life. Instead, our patients are constantly in motion, continually changing through time. Over the short term, there are continual changes in postural orientation associated with locomotion, speech, mastication, respiration and other vital functions. Over longer time-intervals, continuous changes occur during growth and development from infancy to senescence. The complexities of short term and longer-term motion are also well beyond our current ability to characterize directly. Instead, we have developed a clinical convention in which we measure and describe each subject's state instantaneously at one or more discrete points in time and then infer motion or change by the calculation of differences between time points.

As things are now

Even when we limit ourselves to the static description of a single patient at a single time point, system complexity is too great to permit seeing all parts of the craniofacial complex at once. For this reason, the clinician typically decomposes the head non-destructively into a set of graphical abstracts or transforms that can be examined and measured separately. Figure 1 shows the four classical transforms of contemporary

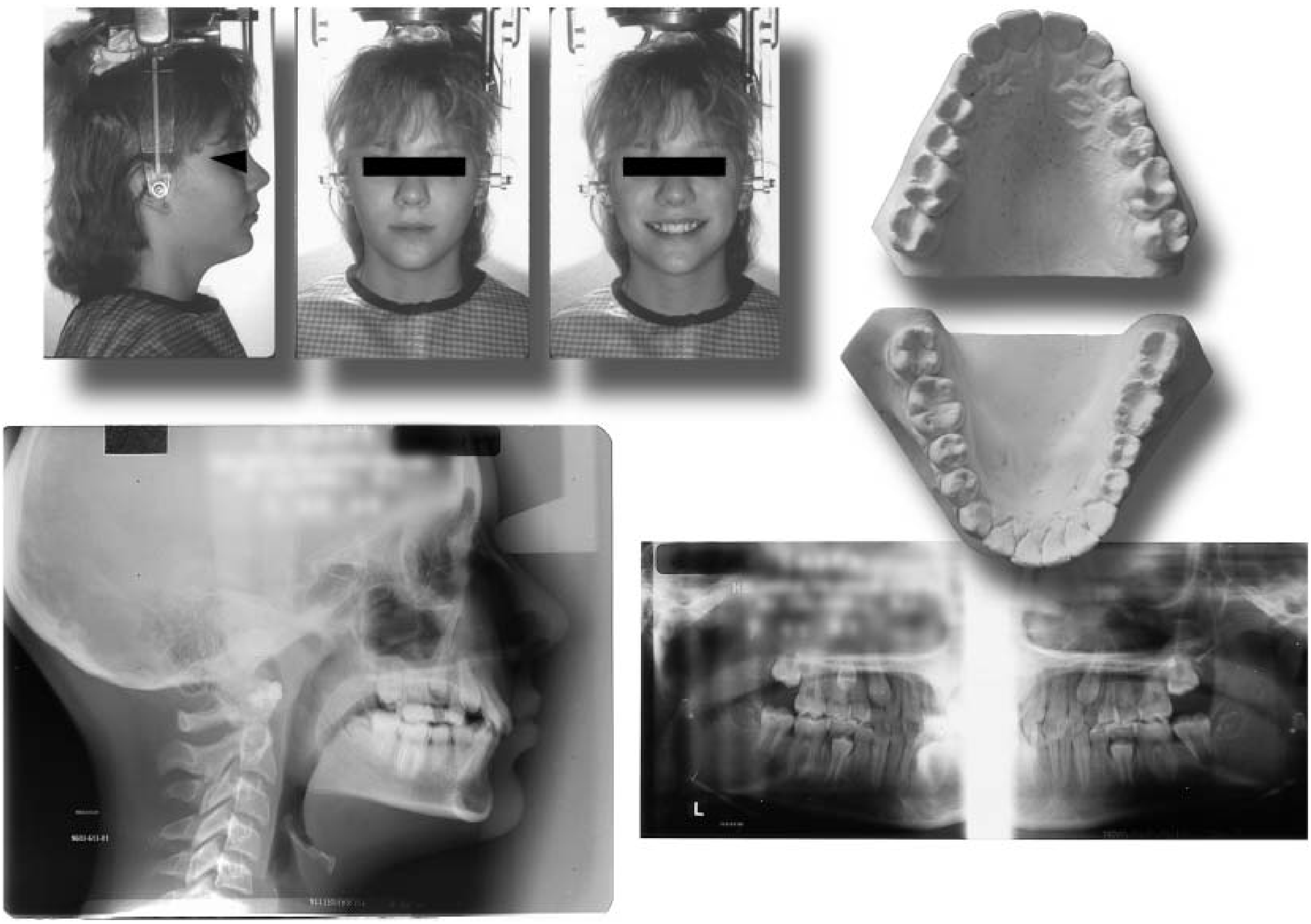

Fig. 1. The four classical transforms of contemporary orthodontic diagnosis and treatment planning.

orthodontic diagnosis and treatment planning – lateral cephalometric X-ray images, upper and lower study casts, facial photographs and intra-oral X-ray images.

Each of these transforms sharpens our ability to perceive part of the information in the system by discarding other equally important information. Thus, study casts allow us to examine the tooth crowns with considerable accuracy, but lose all information about the relationship between the dental arches and the structures that surround and support them. Facial photographs give us excellent information about the soft tissue surface, but lose all information about the teeth and the internal structures of the skull. Lateral cephalometric X-ray images give us attenuated two-dimensional (2D) information about the relationship between the teeth and the bony skull but lose almost all information about the facial surface.

Experienced practitioners know that for any non-trivial orthodontic problem, treatment planning involves evaluation and integration of information from 'all four transforms of the skull'. In contemporary practice each of the four information sources is measured and evaluated separately. But the transforms themselves, as they are customarily generated, contain little or no information on how to reintegrate information from any two or more of them. Therefore, in contemporary orthodontics the clinician is required to reintegrate information from the several transforms 'as a cognitive operation'. Experienced clinicians get fairly good at this conceptual operation and are able to produce rather credible anecdotal case reports for individual cases. The clear advantage of the anecdotal report is that the clinician, on the basis of experience and cognitive skill, links together information from several transforms generated at the same time point and even has some success in linking information from different time points for the same case.

Despite its disparagers, the anecdotal case report does a better job of reintegrating information from several different sources into a single consistent presentation of the whole patient than does any other mechanism now extant. For this reason, the anecdotal case report is a deservedly popular modality for orthodontic teaching and information exchange. But the anecdotal case report as conventionally used does have two severe limitations. First the information it contains is usually collected in a biased way making it unsatisfactory for use in a hypothesis-testing mode. Secondly, because there are no consensually agreed-upon protocols for anecdotal case presentation and no good ways for aggregating non-numerical orthodontic data, it has been difficult or impossible to merge case report information across cases. As a result, the more technically rigorous clinical research investigations in orthodontics have in the past focused almost exclusively on the examination of numerical data from one kind of transform at a time. With few exceptions orthodontic investigators when they do report on grouped data, publish 'either' a paper on lateral ceph data 'or' a paper on study cast data, 'or' a paper on facial photographs, with little or no attempt to merge information across transforms.

Because of this fragmentation, clinical research in orthodontics today bears a striking resemblance to the fable of the blind men palpating an elephant in an effort to establish its true nature. One blind man, grasping an elephant by the tail, reports that the animal is twisted and knotted like a rope. Another, tripping over the beast's firmly planted leg, declares it to be a kind of tree. A third investigator, by chance catching hold of the elephant's trunk, decides that an elephant is a kind of snake. What any observer concludes about the nature of elephants, the author of the fable asks us to understand, depends (to mix metaphors) upon that observer's point of view – which is to say upon which end of the elephant he or she is holding.

The take-home lesson from this extremely powerful cautionary tale is that no complex system can be thoroughly understood when viewed from a single perspective. Although the judgment may seem a bit harsh, the present writer believes that the multi-dimensional perspective of the anecdotal case report is more likely to advance orthodontic understanding than are 'scientific studies' made from the perspective of any single transform. It is simply a truism that complex systems look different when viewed from different perspectives because there is no single perspective from which we can see all of a complex system such as orthodontic treatment presents. Complex systems look different from different perspectives because from each perspective we see different aspects of the same system. These perceived differences are real and are not to be confused with measurement errors.

Figure 2 is a graphic representation of this point as applied to orthodontic research. Model A represents

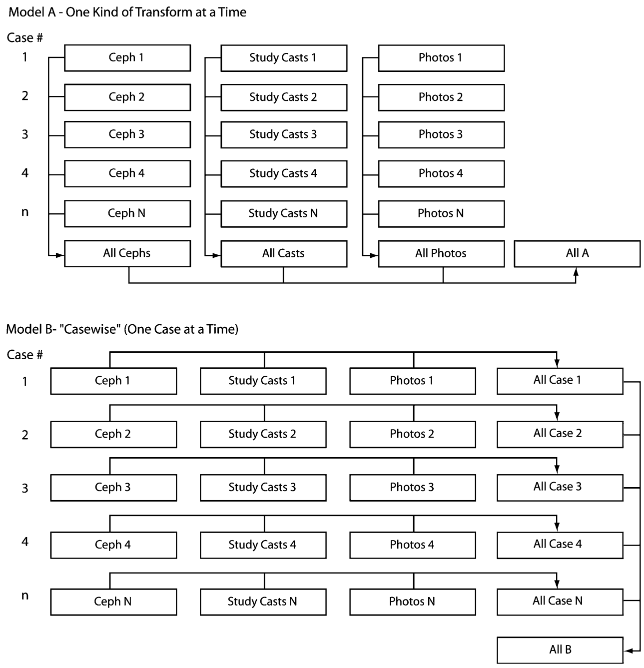

Fig. 2. Two alternative approaches to data handling.

the elephantine nature of most past and current orthodontic research. Typically, one group of investigators examines lateral cephalograms for a series of patients and produces a report from the perspective of the lateral cephalogram. Another team focuses entirely on study casts and produces a separate report examining some class of malocclusions from that perspective. Meanwhile, yet another group of investigators produces a research report based entirely on the analysis of facial photographs. Each group of investigators firmly believes that its perspective is the best one for studying the treatment of malocclusions. And to further complicate the picture, the three groups of investigators are almost certainly examining different herds of elephants!

Model B represents what the writer considers a much more hopeful investigative strategy – what might be called a quasi-anecdotal approach. In this approach, the data from 'all' the transforms and written records of each individual patient are merged and possible on a 'casewise' basis and are treated as a unit. The method approximates the anecdotal case report in the sense that all the transforms/records/data-sources from each single patient are treated as a single entity. However, it differs from the anecdotal case report in the sense that the judges who acquire data from the records are blinded with respect to the associations between the different within-patient data sources during the data acquisition process.

In the past, the conduct of true 'casewise' research in clinical orthodontics has been so prohibitively difficult logistically as to be practically impossible. But today the possibilities are rapidly changing, as we consider in the next section.

As things are becoming

The development of two very different but ultimately complementary computer-based modalities is now beginning to enhance the possibilities for examining the complex orthodontic domain simultaneously from multiple perspectives. The first is the development of user-friendly software for the building of searchable relational databases of the type alluded to in model B above. In the past, orthodontists, like specialists in many other fields, have tended to confuse the idea of a registry of treatment records with a database. Reflection will reveal that the set of records that exists in the clinical practice of any orthodontist with more than 10 years' experience vastly exceeds in information content the total amount of quantified data currently available to the entire orthodontic specialty. To construct a true database from such a records registry, a very large number of measurements (i.e. 'data') must be abstracted and organized. The work involved is tedious and demanding and must be done in an unbiased manner with extensive replication and error checking. In addition, the resulting data must be organized for rapid and efficient searching along any variable or combination of data variables derived from any transform or combination of transforms. At minimum, such a database should include information from pre-treatment and end-of-treatment copies of all the transforms depicted in Fig. 1 (or their 3D equivalent) plus information abstracted from written treatment records of various sorts. Note that the examination any new combination of variables drawn from such a database would be tantamount to looking at the orthodontic world 'from a new perspective'.

Five years ago, the idea of such a searchable relational database of orthodontic treatment data might very well have appeared to the casual observer to be an unreachable fantasy. Today, the public's daily contact with Google™ and Amazon® establish conclusively that truly practical mechanisms for intensive data acquisition and database searches exist. Indeed, electronic 'data mining' has already become recognized as an independent sub-specialty within the fields of statistics, epidemiology and computer engineering. With assistance from the AAO, our group at the Craniofacial Research Instrumentation Lab at the University of the Pacific Department of Orthodontics has been hard at work developing a prototype orthodontic database of just the type described. It is a relatively primitive work-in-progress that currently contains searchable data for only a few hundred cases. But it is already openly available on the internet at http://www.cril.org and has already proved useful in orthodontic education and research. We invite you to examine our web site, but remember that it is a work in progress, constrained thus far by limitations in available resources.

The second computer-based modality that will facilitate our ability to examine the complex field of orthodontics simultaneously from multiple perspectives is the development a vastly improved method for conducting true integrated 3D craniofacial investigations called cone beam volumetric X-ray tomography (see Fig. 3).

This newly available modality makes it possible to capture the information formerly contained in several kinds of conventional orthodontic transforms (e.g. lateral ceph, panoramic and periapical dental X-rays, and facial surface in grayscale) in a single perfectly registered 3D digital file. Because data through the entire volume of the head is acquired in one pass without the need to reposition the patient, the problem of merging data from different transforms accurately is effectively eliminated.

Currently available digital X-ray machines that employ the cone beam method show great promise but have consequential limitations for orthodontic use. Their field of view is too small to permit capture information from the full face and cranium in a single exposure, and their effective resolution (spatial and gray scale) is well below that of conventional 3D X-ray systems. But technical advances in this field have accelerated rapidly and it seems reasonable to expect that within the next 2 years the format size of the image will permit full size lateral ceph projections. Spatial resolution throughout the volume of the skull is also increasing. Indeed, it is not unlikely that within 5 years it will be possible to generate the 3D digital equivalent of upper and lower study casts automatically as part of the same exposure from which ceph, panoramic and periapical views are created.

As things should be

Like practitioners of every other clinical specialty in medicine and dentistry, we orthodontists can fix empirically more things than we really understand. From the perspective of immediate service to the public, that is really a good thing, because none of us really understands all that much about the way the complex systems we are called upon to minister to really works. But if orthodontics is to assume the status of a really scientific discipline, it is not enough to be able to fix malocclusions by what are in essence trial and error methods. Rather, in addition to our present pre-occupations, we must strive to understand at a more fundamental level what it is that we are fixing.

We can reasonably expect that near-term advances in instrumentation discussed earlier will soon bring us searchable databases and reliable systems for making integrated volumetric measurements of the head in three dimensions. These advances will certainly improve our ability to measure the morphologic 'status' of the skull and teeth at discrete time points during growth and treatment. However, we should not delude ourselves into believing that they will greatly increase our understanding of the fundamental 'processes' of growth and of response to orthodontic treatment. Rather, they represent a continuation of our specialty's focus on static analysis in lieu of the study of the biological processes of change and motion through time.

Since E.H. Angle's *Latest and Best* paper in 1927 the *techniques* of orthodontic treatment have advanced dramatically. Pre-fabricated appliances and arch wires, vastly more efficient methods for luting fittings to the teeth and for later removing them, removable tooth positioners and their successor, the Invisalign appliance, computer-aided cephalometric analyses and computer-morphed 'VTO' displays, have developed at an increasingly rapid pace – at times with almost breathtaking speed.

But at the level of theory – the development of a generalizable understanding of the causes of malocclusion and the biology of treatment, we have truly made little progress. The same two fundamental biological prob-

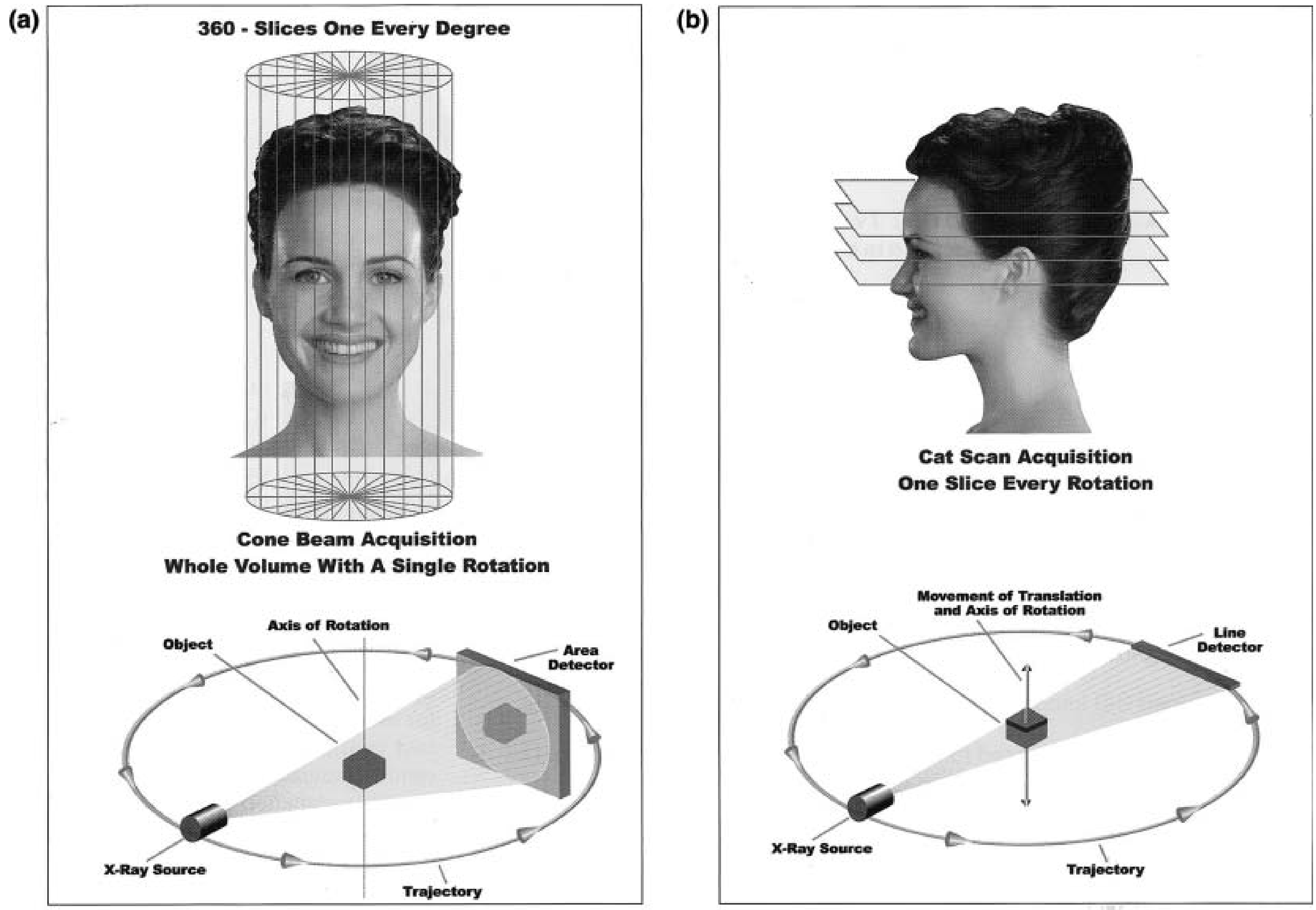

Fig. 3. Differences in image acquistion between (a) cone beam volume tomography and (b) traditional computed tomography (courtesy of Dr Ivan Dus and Dr Carl Gugino, Aperio Services Inc., Sarasota, Fla).

lems that puzzled Oppenheim, Hellman and Angle remain so intractable that they are all but ignored by contemporary investigators. So I choose to restate them here, if only to keep us all appropriately humble.

The first is the problem of understanding the fundamental biology of tooth movement – the mechanism by which a mechanical load delivered by a wire or elastic is transduced into a set of biological instructions that cause teeth to migrate through bone. Note further that the success of our ministrations requires that the force-induced instructions trigger substantial remodeling of bone with relatively little change in the hard tissues of the teeth themselves. The second fundamental biological problem in orthodontics occurs at the far end of treatment – it is the problem of post-treatment stability.

In the modern organization of the biological sciences, these two problems belong to two different categories of inquiry. In the old days, before approximately 1950, biology was customarily divided horizontally into two domains – Botany, the study of plants, and Zoology, the study of animals. Today, biology is customarily divided vertically into two different categories – the study of the constituent elements of both plants and animals, typically referred to as 'Molecular and Cellular Biology', and the study of higher-level organization of the elements of both plants and animals, typically termed 'Systems and Integrative Biology'. In both areas, interest has moved beyond classification and gross morphology. Primary interest has shifted to the study of process, of how biological events are organized and sequenced, studied quantitatively at high precision.

The investigation of how mechanical loads to teeth are transduced into instructions to remodel alveolar bone belongs in the domain of 'Molecular and Cellular Biology'. Although the details are still quite obscure and are likely to remain so for some time, the outlines of a future understanding are already discernable. They depend on the recognition that the cells of connective tissues like the PDL and alveolar bone are not 'bags of water with solid inclusions and dissolved chemicals' as they appeared to be at the time of Sicher and Brodie, but instead contain relatively rigid cytoskeletons with equally rigid connectors to the extra-cellular matrix in which the cells are embedded. Orthodontists are well equipped by education to understand the idea that external loads upon such cytoskeletons would produce mechanical stresses and strains that could be transduced into biological instructions. But we are probably not equipped by education to make fundamental contributions to the study of 'mechanotransduction', as this developing subspecialty of bioengineering and computational biology is already called. Here we must probably content ourselves in the future with the role of interested onlookers.

But with regard to the second longstanding problem in orthodontic understanding, the question of post-treatment stability, the younger generation of orthodontists will have to fine a way to take the lead. The investigation of post-treatment stability, like most problems in clinical orthodontics and clinical medicine, belongs in the domain of 'Systems and Integrative Biology'. It calls for a top-down analysis and solution, based on a global overview, as distinguished from the incremental, bottom-up kind of solution that seems appropriate for the investigation of the mechanotransduction problem. Despite a century of concern, we have very little traction on the problem of stability, even less than we appeared to have before the work of Little et al. But at least we can describe it in somewhat more general terms than before:

At the outset of treatment, the biomechanical relationships between the teeth and the hard and soft tissues that surround them are in fairly much a steady state equilibrium. We may not like the appearance of our patient's dentition at initial presentation, but it is a pretty good bet that, despite some modest oscillations, the occlusion will not undergo substantial 'spontaneous' change during growth. Thus, we can appropriately characterize the occlusion prior to treatment as being fairly much in a state of static equilibrium. Because we do not like the extant occlusal relationship, we perturb the system by introducing a disturbance that we call 'treatment'. At the end of treatment we have altered the original equilibrium and moved the system to a different organizational level. If the new level represents a new equilibrium, then the system will continue in a new steady state. We call such a state 'a stable outcome'. But if end-of-treatment conditions are not at equilibrium, then the system will tend to rebound toward its original equilibrium, a condition that we call 'relapse'. The conceptual problem for the orthodontic clinician, fundamentally unchanged since the time of Angle, is to differentiate in advance between patients and treatments that will be stable at outcome and those that will rebound ('relapse') toward their pre-treatment state. And at present, we have essentially no way to make that distinction.

Conclusion

At the risk of appearing to be a spoilsport, I had expressed strong reservations about the narrowness of outlook that characterizes contemporary orthodontics. Our technical prowess has expanded exponentially and we have little difficulty in meeting the short-term demands of our clients, but there is real danger that we may be setting our sights too low as an intellectual discipline. For at least its past 20 issues, the cover of the *Ajodo* has almost invariably featured the picture of a well-scrubbed girl or young woman with an 'attractive' smile. Should this be the 'total' focus of our specialty? Have we gone from being 'profilests' to being mere 'cosmetologists'?

I certainly hope not! Smiles are indeed important, but they should not be allowed to become the alpha and omega of orthodontics. Today our tools for investigating, understanding and ameliorating the physical and social consequences of malocclusion are more powerful than they ever have been and are increasing in power exponentially. We should use those tools to the fullest to gain a more profound understanding of our subject, the whole patient in continuous interaction with his/her physical and social environment.