The Case Against Biomechanics

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When one examines present-day courses in orthodontics at the graduate level, one is aware of a change in their character. The subject matter has increased greatly in complexity from what it was several decades ago. To be sure, the basic sciences such as anatomy, histology, pathology are still taught; growth and development, and principles of occlusion are still carefully considered. In addition, students acquire technical skill in appliance construction and spend long hours in the clinic treating cases.

But, to these time honored subjects some new course material has been added, among which may be mentioned cephalometrics which has become firmly established as an important tool for diagnosis and research. Statistics which are heavily weighted with multitudinous formulae for evaluation of research data, and biomechanics or biophysics which, through the inclusion of sizable segments of engineering mechanics in its subject matter, have contributed still further to the complexities of the orthodontic curriculum.

The emergence of the latter science with its incorporation of the principles of analytical mechanics into appliance design is a comparatively new development in orthodontics.

To illustrate the manner in which this change has taken place one has merely to refer to the old catalogues of one leading orthodontic department which, many years ago, offered a course called Mechanics of Appliances. Ten years later the same course was designated Biophysical Principles and, recently, we see it renamed Biomechanical Principles.

What took place during these years to justify the change in name? Did the knowledge of appliance design improve to such an extent that a new designation was called for? Was something valuable added to the armamentarium of the practitioner in that he could now manipulate force diagrams, vector analyses, definite integrals and formidable formulae of integral and differential calculus in planning mechanotherapy? An examination of several recent orthodontic textbooks may shed some light on this matter.

One author, in his excellent text, has this to say: "Moving teeth, well - directing them into healthful esthetic and functionally stable positions with a minimum of discomfort or other undesirable effects is one of the most difficult and exacting procedures in all of dentistry. Those who have devoted their lives to the problem find new challenges around every corner, but with the ultimate panacea always moving farther out of reach."

Why does the solution elude us? Teeth, after all, are relatively easy to move. But, asserts this author, "clinical results, even though they are the final objective of treatment are grossly unreliable as criteria for evaluating the effectiveness of mechanical appliances."

Even though the appliances may be properly designed, many external variables influence the end result. Among these may be mentioned the skill of the operator, the cooperation of the patient, the tissue response and the limitations of the morphogenetic pattern.

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Thus, the author continues, it seems evident that a wide gap in our knowledge has seriously handicapped our specialty in evaluating and using the forces generated by its mechanical appliances. But, this gap can be readily closed by our allied science of engineering and, concludes the author, we have to study what he calls orthodontic engineering to which he then devotes a section of his book.

Another textbook which also deals with these matters starts out with the statement that "the goal of orthodontics is the correction of malocclusions and the placement of teeth in such positions that their own *functional dynamics* will tend to maintain the correct occlusion. Attainment of this goal depends on successful moving of teeth." Then follows 125 pages of analytic mechanics, dynamics and strength of materials in which the text leans heavily on mathematical and physical concepts involving force diagrams, integral equations of the calculus, vector analysis, and so forth.

One may speculate how palatable this array of complicated technical knowledge would be to a fledgling orthodontist who, rather appalled and overwhelmed by this ponderous mass of data, may be led to wonder how relevant it really is to the problem of moving teeth.

It is the contention of this paper that the combination of biology and mechanics implied in the term biomechanics has not fulfilled its promise. This failure has been due to a distortion of the meaning of the term itself. In slanting the use of the term toward biology, we have excluded an important area of mechanics, namely, the forces generated in the bone and the contiguous dentofacial complex. It seems apparent that only a part of the forces involved in moving teeth have been considered. We will argue that a different approach to the problem of the relation between mechanics and biology will result in a new orientation with the emergence of a new concept of biomechanics to replace the adumbrated concept as it exists today! To this task we now proceed.

The mechanics of the edgewise arch mechanism, as Dr. Angle explained it, seemed fairly understandable. The underlying idea was to construct an ideal arch fashioned of a suitable gold alloy which was placed into position alongside the malaligned teeth which were then slowly ligated to their desired positions.

The ideal arch was properly contoured and torqued so that by the time bracket engagement was secured, the several teeth were properly aligned, with their axial inclinations satisfactorily corrected and, following achievement of the desired mesiodistal relation, the case was ready for retention.

So successful was the edgewise arch as a force mechanism that very little modification of the archwire was needed. For many years, it functioned satisfactorily and, except for the subsequent introduction of the vertical loop, it was not modified from the form which Dr. Angle had impressed on it. Many successful cases with healthy, esthetic dentures still stable twenty to thirty years out of retention attest to the efficacy of this old method. Strangely enough, no quantitative evaluation of the forces used had been made. Men had learned to use the resources of this mechanism from empirical experience, buttressed by an infinite care and feeling for what they called the proper use and conservation of anchorage - then, as now, a vague term.

This idyllic state of affairs was rudely shattered by the staccato of popping bicuspids which ushered in the extraction era. The need to close extraction spaces quickly, plus the change from gold archwires to steel fabricated appliances and the popularity of the Tweed philosophy with its advocacy of "toe-hold anchorage preparation", became the order of the day. Light round steel wires replaced the rectangular arches. Steel manufacturers hired engineers to design steel wires that would function as effectively as the gold wires. This problem was easily solved, and now the manufacturers began to publish diagrams showing the amount of force generated by various diameters of springs and various types of elastics. The basis for quantitative information relating to the application of force in relation to mathematics and physics had been laid.

The culmination of this trend came with the impact of the Begg light-wire technique which took as its point of departure the experiments of Storey and Smith who purported to demonstrate that force against an anchor molar did not displace that molar forward if it was kept below a certain value; exceeding this value caused the molar to tip forward.

This led to the differential force concept which insisted that forces be quantitatively evaluated, and it was not long before courses in engineering mechanics began to appear in the curricula of the orthodontic departments of several universities. These courses were heavy fare indeed. They dealt with force diagrams, vector analysis, calculus of moving bodies, deformation and stresses and so forth. It was not until later that textbooks with chapters devoted to engineering mechanics appeared and exhibited the same array of physical formulae, to the dismay of many orthodontists who found themselves caught between the Scylla of cephalometrics with its multitudinous systems of evaluation, and the Charybdis of the complicated differential equations of what had now become biomechanics or biophysics.

Somehow, the notion prevailed that these esoteric disciplines would enable the orthodontist to move teeth more intelligently, more physiologically and more efficiently with better consideration for the biologic substratum upon which the forces calculated by the formulas of engineering physics were to act.

The net result of all of this activity was to substitute for the ideal arch of the original edgewise appliance an appliance containing a bewildering array of bends and curlicues, of helices and loops all built on a force system of great complexity, difficult to control. Anchorage was seldom conserved and then with difficulty. In fact, bending an archwire for phase three of the Begg technique is a most difficult, exacting, and time-consuming task and one fraught with danger as a result of the complexity of forces released.

Although our knowledge of engineering mechanics may be sophisticated and our fabrication of mechanism to move teeth adroit and competent, when the appliance is placed on the teeth and force applied to the living tissue, the inadequacy of our efforts becomes apparent at once.

For there are forces in the underlying continuum of tooth, bone and muscles that directly oppose the forces of the appliance. Biomechanics should have some knowledge of these oppositional forces; unfortunately, its knowledge of them is most scanty. It seeks to understand the forces generated in the substratum by studying the histologic responses to the applied forces, rather than the forces themselves. But these histologic changes do not relate to mechanics; they relate to biology which is a different science. The subject matter of biomechanics should properly be confined to physical forces, both outside and inside the biologic continuum. Why study so intently the external forces and neglect the internal forces? In the final analysis the response of the bone is due to the action of internal as well as external force systems which play on the tooth root, and act by means of the summation of myriads of small, infinitesimal impulses generated in the bone tissue and in those cells which are to differentiate into osteoblasts and osteoclasts. We should like to know more about these forces, how they are acting on these cells and if they can be resolved into meaningful resultants.

Recent research as reported by Bassett suggests that weak electrical currents are generated in bone when it is deformed and that these currents are responsible for the remarkable plasticity of bone. These electrical forces may properly be included in the internal forces acting within bone.

These investigators found that the remarkable property of bone to adjust itself to mechanical stress in accord with Wolff's law, even though it was composed largely of hard, unyielding crystals, was due to the piezo-electric properties of its elements. A piezo-electric property simply means that when the bone elements are pushed so that they are bent, small electric currents are mechanically generated within the bone; these currents influence certain cells so that they become osteoblasts or osteoclasts possibly through the flow of nutrients. There are three elements of bone that generate these weak electrical currents when they are stressed: First, there are the fluorapatite bone crystals; then there are the collagen or organic components; and finally, the interface between the crystals and the collagen acts as a semiconductor to direct the electrical flow in the desired direction depending on its polarity.

The whole system may be thought of as constituting a negative feedback system consisting of three parts:

1. A signal from the environment which could be supplied by pressure from the orthodontic appliance.

2. A transducer to convert the signal into a meaningful biologic response.

3. The response itself. This response occurs according to Wolff's law.

The foregoing considerations suggest that the well-known response of bone to applied force as explained by Oppenheim and his successors is incomplete. This response was usually depicted by histologic slides which represented sections through the tooth in only two planes of space. Actually, the process takes place in three planes of space and, moreover, is a random phenomenon. Conceivably, the crystals of bone differ in different patients so that the behavior of the cells, which act randomly, would vary from case to case. Tooth movement is ordinarily pictured as being in a straight line, but this is not the case. The response, while in the general direction desired, would vary in that sometimes the tooth would tip, while in other cases it would tip and rotate, and, in a third instance, it might move bodily. It is the randomness of the action of the microscopic forces acting on the cells that causes the variation of responses, a phenomenon familiar to all of us. It would seem that the final reaction of the tooth does not depend entirely on the magnitude of the forces being applied to it.

Another internal force which acts through a coalescence of a myriad of tiny forces is that of growth. We are accustomed to draw a diagram of a mandible and represent growth with a large arrow to indicate a downward and forward vector of large size in the ramus and pointing toward the chin point. But, contrariwise, we should rather think of growth as the result of the sum total of a myriad of small forces exerted by osteocytes, osteoblasts and osteoclasts acting randomly, some downward, some forward, some backward, with the net result that a resultant forward and downward vector is generated. We can approximate and hypothecate these forces by using the techniques of that branch of physics known as statistical mechanics, a discipline which deals with aggregates of small objects such as atoms or molecules, in this instance with cells, and utilizes the laws of probability to explain how these aggregates act.

Another field where biomechanics can conceivably collect data as to the forces of the continuum, is to relate the data of electromyography to actual muscle pressures on the denture as determined by sensors and transducers. These can then properly be related to the external forces of the appliance and results determined. In fact, appliances to measure delicate forces in the biologic continuum are already being used and their application to the determination of hidden forces in the dentofacial complex seems only a matter of time. I refer to an electronically, sophisticated talking tooth which has been developed at the University of Michigan by Ash and Scott.

This talkative tooth, although it is packed with six miniature radio transmitters, twenty-eight electronic components with special bondings, and two rechargeable batteries, looks deceptively like an ordinary first molar "bridge." When inserted in a patient's mouth, however, it not only can chew food, but also can measure the pressures and directions of forces impinging on its surfaces, and then it can broadcast detailed information to waiting monitors which consist of six telemetering devices.

More than two years of planning and assembly went into the tooth transmitters. The University of Michigan researchers, supported in their work by grants from the National Institute of Health, had to develop a number of refinements in miniaturization and telemetry before they could bring this concept into reality.

All of the foregoing activities are properly the province of biomechanics for the forces on both sides of the force equation are determined, on one side the mechanics of wire in configurations and on the other the inherent oppositional forces which develop as the result of pressure in accordance with Newton's third law.

While these oppositional forces are admittedly difficult to assess or even to measure, it is well to remember that their determination would lead to the solution of a central problem in orthodontics, the problem of retention.

We often hear that a denture is said to be stable when all the forces, external and internal to it, interact with each other in such a way that their algebraic sum is zero. This is a static concept and disregards the fact that a retained denture exists in time as well as in space. For a denture, even when in retention, is not a static system. In fact, we should conceive retention as the placing of tooth elements in such a relation that the normal or acceptable occlusion of the end result will not relapse as long as the denture continues to be affected by the multiplicity of forces that play upon it. In this situation growth would act to give a positive impetus to reinforce these balancing forces over the time gradient.

In this connection slow treatment might give more retention than fast treatment, because during the longer period the favorable growth vectors would operate favorably toward an acceptable result.

In conclusion, we have examined certain aspects of biomechanics and have called attention to a hiatus in its subject matter. We have indicated the direction which should be taken in the further development of this discipline. Under no circumstances is our assessment to be construed as advocating that biomechanics should be dropped from the orthodontic curriculum. On the contrary, orthodontics today finds itself in the midst of the greatest explosion of knowledge in the history of man. The quantity of information is doubling every ten years. Increased complexity goes hand in hand with the new technology which is emerging. Biomechanics will contribute its part to this rising wave of complexity.

Inevitably, the orthodontic technology of tomorrow will differ vastly from the mechanotherapy of today. Conceivably the computer will become part of the armamentarium of the orthodontist of the future. Data regarding all relevant factors in a situation, collected by elaborate sensors and transducers, will be fed into a computer which will then make a diagnosis and give suggestions for treatment, even to designing the appliance.

In spite of this vast change in technology, however, the dentofacial complex will continue to develop according to its inherent morphogenetic pattern. At present, we know but little of what this pattern consists and how it acts through the forces of growth and development. To invoke teleology or to say that nature is fulfilling itself is merely to appeal to quasi-religious dogmas difficult to justify.

The best tool we have to attack this problem of the nature and manner of unfolding of the pattern is to use the disciplines of the scientific method. Only through the application of these modalities, nurtured by the explosion of knowledge, refined by the breakthroughs of the space age, reinforced by a greatly expanded technology, can we ever hope to penetrate to an understanding of the infinitely varied and complex problems posed by the forces which make up that elusive entity known as the dentofacial complex.

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