On tooth movement

Robert J. Isaacson, DDS, MSD, PhD; Steven J. Lindauer, DMD, MDSc; and Moshe Davidovitch, DMD, MMSc

Biologically based tooth movement studies recognize that inter/intra/extra-cellular interactions are ultimately responsible for physical tooth movement. Such interactions include the 'coupling' phenomena of bone resorption and formation[1] with its associated local factors,[2-10] systemic hormonal control of bone-cell activity,[11-15] as well as responses to endothelial,[16] neural,[17-19] inflammatory,[20,21] and immune signals.[22] Investigations have also been focused on alveolar bone as an organ.[3,24] This characterization of bone has been analyzed employing ionic (electric) currents,[25,26] whether stress-generated[27] or actively administered,[28,29] to affect tooth movement. In addition, bone metabolism has been investigated with regard to the direct influence of force-dependent tooth movement on alveolar response.[30] The common factor throughout many of these types of studies is the use of mechanical forces, or the signals they evoke, to elicit the experimental response(s).

Orthodontic tooth movements are currently described using biomechanical Newtonian mathematical models which explain tooth movement from a pure physics point of view where only two possible ways exist to apply a force system to a tooth.[31] The first is by a single force, which in practice almost never acts through the center of resistance. Therefore, a single force results in displacement of the center of resistance in the direction of the line of the force and tipping as shown in Figure 1. This tendency for rotation is called the *moment of the force* whose magnitude is equal to the magnitude of the force multiplied by its perpendicular distance from the center of resistance of the tooth. This endows the moment of the

Abstract

Current concepts of clinical orthodontic tooth movement are misleading. Traditionally, these have been described as dependent on force levels and being tipping/bodily in nature. The following is a reevaluation of the relationships between tooth movement and orthodontic mechanotherapy not usually considered when analyzing tooth movement clinically.

It is our contention that confusion as to the biological response(s) to mechanical force is derived from *in vivo* orthodontic trials where conditions are undefined. This correlates with variable biological responses within the periodontium.

Constantly changing moment to force ratios inherent to the dynamic load deflection rates of any system used to move a tooth cause changing tendencies for crown/root tipping. This implies that the accepted notion of static translatory tooth movement, although a useful didactic concept, is currently unattainable. In actuality, it has never been documented empirically using any conventional orthodontic appliance.

Key Words

Tooth movement • Orthodontic • Mechanotherapy

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Figure 1
A two-dimensional schematic representation of a typical orthodontic point force applied away from the center of resistance. This creates a tendency for rotation referred to as the *moment of the force* (M_F), causing the resultant proportional distribution of strain in the periodontal fibers represented by the lines of tension radiating from the root. This application of a force will cause the center of resistance (o) of the tooth to move parallel to, and in the same direction as, the force. The center of rotation (X) will be located apical to the center of resistance (o).

Figure 2
A two-dimensional schematic representation of the application of a pair of equal but opposite parallel noncolinear forces, i.e. a couple, as typically applied in orthodontics. These forces act to create a rotational tendency, referred to as the *moment of the couple* (M_C). This causes a distribution of strain in the periodontal fibers as shown. The center of rotation and center of resistance (o) are always coincident and not displaced by M_C.

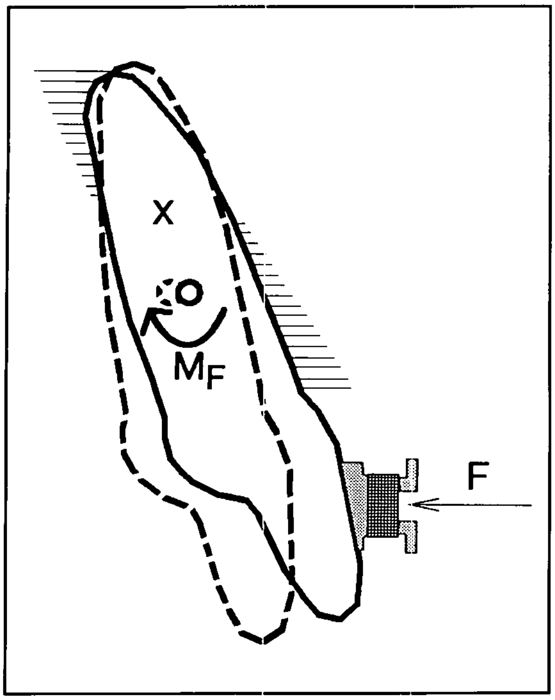

Figure 1

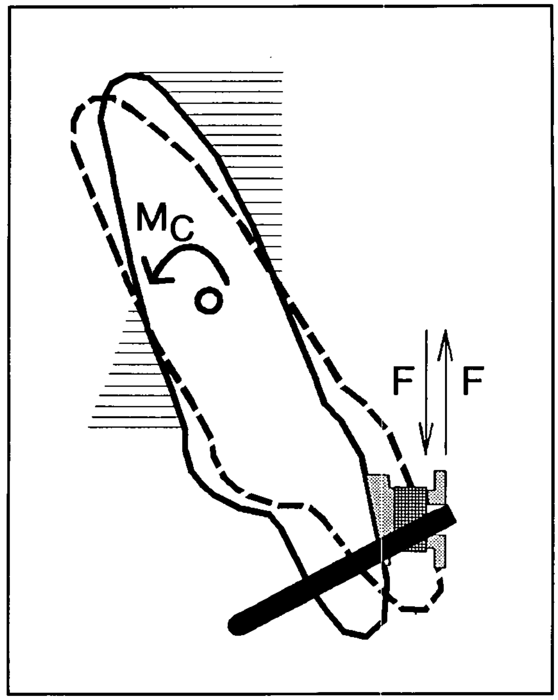

Figure 2

force with a clockwise or counter-clockwise 'sense' (direction) around a center of rotation which will always be apical to the center of resistance of the tooth.

The second method by which tooth movement can be effected is through the application of a pair of equal forces which are parallel, noncolinear, and of opposite direction, termed a couple (Figure 2). This system, applied anywhere on a tooth, creates only a tendency for rotation referred to as the *moment of the couple* whose magnitude is equal to one of the forces of the couple multiplied by the inter-force distance. The center of rotation resulting from the moment of the couple is always coincident with the center of resistance of the tooth irrespective of its point of application.

Connoting teeth as rigid bodies, and accepting the limitation that orthodontic forces do not act directly through the center of resistance, all appliance systems must cause tooth movement through one of these two processes, either alone or in combination. The traditional paradigm describes tooth movement as rotational (tipping) and/or translational (bodily movement), as shown in Figures 1 and 3.[32] Figure 1 depicts the effect of a single force whose point of application is away from the center of resistance. This configuration causes rotation or tipping, with the center of resistance moving parallel to the line of force.

The latter descriptor of tooth movement, that of translation, is somewhat more complex (Figure 3). Here, as with rotation, the force is applied away from the center of resistance, again causing rotation or tipping. However, for translation to occur there must concurrently exist a couple with an opposite sense tending to tip the root in the opposite direction as the crown. Under these conditions, the relative amount of crown tipping (moment of the force) and root tipping (moment of the couple) expressed at any given moment in time determines the location of an instantaneous center of rotation. When these two oppositely directed moments are equal in magnitude, the center of rotation is at infinity and tooth translation occurs (Figure 3). This determinant is also expressed as the moment to force ratio.[31-33]

It is important to realize that no empirical or experimental evidence has ever been reported to verify this concept of tooth translation. Any anecdotal time-lapse radiographic 'evidence' of changes in tooth position without alterations in inclination does not prove the mathematical concept of translation. With existing appliance systems, the force and its accompanying moment to tip the crown are derived from activation (deformation) of one part of the appliance system that has its own particular load deflection rate. However, the moment of the couple to tip the root is derived from one or more different components of the appliance system endowed with its own unique load deflection rate. Since the decay rates of the moment of the force and the moment of the couple are not equal, the ratio between them constantly changes.[34] This results in continuous repositioning of the (instantaneous) center of rotation. Therefore, *in vivo* the biomechanical concept of

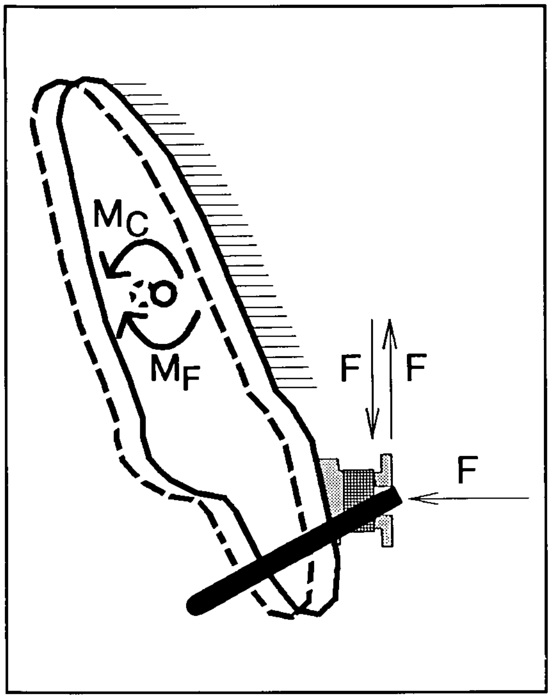

Figure 3

translation can only exist instantaneously, and cannot be sustained over time by any existing appliance system.

As a consequence, a continuously changing pattern of strain will exist throughout the periodontal ligament (Figures 1-3). This in turn influences the responses within the periodontium.[35,36] Continuous variability in the quality/quantity of periodontal strain is not consistent or compatible with the concept of parallel tooth displacement[33] (Figure 3). In reality, the illusion of translatory tooth movement requires ongoing clinical titration of the moments of the force and the couple. In turn, the constantly changing pattern of periodontal strain should be expected to evoke variable biological responses in the periodontal ligament and its associated structures.

The orthodontic literature is replete with examples of the concept that compressive and tensile forces, with some relation to duration and intensity, elicit varying biological responses.[35-45] This dogma is firmly rooted in the early work of Reitan (1947) where histologic 'evidence' is produced to promote the notion of "bodily tooth movement".[46] Examples are cited of fractions of the root surface area behaving as expected according to the above theory (Figure 3). However, given the previous contentions it seems just as plausible (if not more so) that when mechanical forces are used as stimuli in tooth movement studies, the specific quantity, and in some instances even the quality, of the strain transferred to any given portion of the periodontium varies continuously and is indeterminable. Fluctuations in the quality/quantity of these forces during their application could impact further on these responses in an inconsistent manner. Moreover, the resulting temporal overlap of these responses increases the difficulty in interpreting the corresponding biological findings. This use of a variable stimulus will impact reproducibility as well as applicability of any data gathered. That the need for a constant quantity/quality of mechanical force is recognized as desirable in orthodontics[34,47,48] is evidenced indirectly through the evolution of orthodontic materials. For example, the super-elastic property of NiTi alloy wires is touted as being able to "generate a physiologic tooth movement because of the relatively constant force delivered."[49]

It is unrealistic to expect tooth displacement to occur in any manner other than crown movement exceeding root movement (i.e. the moment of the force exceeding the moment of the couple), or *vice versa*. In this way tooth movement is analogous to alternating current (AC), whereas the idealized version is likened to direct current (DC). The net result is that the periodontium is not homogeneously affected as described by an idealized model (Figure 3). In fact, this mathematical ideal probably only rarely occurs, and if/when it does it is only momentary in duration. Clinical tooth movement is accompanied by a constantly changing spectrum of strain in the periodontium that ranges from compression to tension. In order to gain an understanding of the biological mechanism(s) of tooth movement, carefully controlled appliance systems or measures of strain in the periodontium are important to meaningfully relate the stimulus of periodontal strain to the biologic events recorded.

Figure 3
A two-dimensional schematic representation illustrating the traditional theoretical concept of *translation*. The rotational tendencies of the moments of the force and couple, being opposite in direction and equal in magnitude, will nullify each other. The remaining force will tend to cause tooth movement in a bodily manner, and result in a uniform distribution of strain in the periodontal fibers as shown.

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Commentary: On tooth movement

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This well-written article provides some insights into new concepts related to biomechanics and biology of tooth movement. The authors contend that currently held opinions on constant and "static" moment to force ratios and their associated types of tooth movements may not be valid since moments and forces in orthodontic force systems vary as the tooth moves and the appliance deactivates.

The concept of dynamically changing moments and forces is logical and, indeed, has been discussed previously (Burstone C. Am J Orthod 1982; 85:361-378). However, what the response of the periodontal tissues is to these variable moments and forces has not been adequately developed or discussed in this article. It is possible, using information currently available in orthodontic and orthopedic literature, to further develop this concept.

With regard to translational and tipping movements, one generally considers these to be the net result of an activation as observed by the clinician at the next activation visit. It is highly likely that in the time between activations a variety of types of tooth movements occur, but the end result is dependent upon what the average moment to force ratio was over the period between activations. Therefore, although the moments and forces may vary over time, their net result between visits is largely determined by the appliance design and the activation. The above discussion highlights the differences in our understanding of the definition of the words translation and tipping tooth movements, and is not meant to detract from the concept proposed by the authors on variable moments and forces and their related tooth movements occurring between visits.

In summary, although this paper examines the concepts of biomechanics and tooth movement from a new perspective, it lacks further development of these concepts. The proposed concepts need to be further validated with information available from other current literature in orthodontics and orthopedics. Furthermore, a greater synthesis of this information would also provide a stronger rationale for the proposed concepts.

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