Pitch, roll, and yaw: Describing the spatial orientation of dentofacial traits

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The value of systematically enhancing the Angle classification by including transverse and vertical characteristics in addition to anteroposterior relationships for the face and the dentition is universally accepted. Three aeronautical rotational descriptors (pitch, roll, and yaw) are used here to supplement the planar terms (anteroposterior, transverse, and vertical) in describing the orientation of the line of occlusion and the esthetic line of the dentition. Each of the latter traits affects the modern clinical practice of orthodontics because of its greater focus on dentofacial traits beyond the correction of malocclusion. Consistent with the principle that every orthodontic intervention should begin with a thorough consideration of variation in a patient's dentofacial traits, this article offers further refinement of diagnostic description and classification. (Am J Orthod Dentofacial Orthop 2007;131:305-10)

In 1969, Ackerman and Proffit¹ proposed that the Angle classification be systematically strengthened by evaluating dental and skeletal relationships in all 3 planes of space, not merely in the anteroposterior dimension. Since then, orthodontists have largely adopted this suggestion in some fashion. The purpose of this article is to add yet another dimension to the description of spatial relationships in the dentofacial complex. Its value relates to the increased emphasis now on soft-tissue considerations, the application of 3-dimensional (3D) imaging in clinical practice, and technologic advances such as the use of temporary skeletal anchorage that have potentially opened new treatment possibilities.

New influences on orthodontic diagnosis and treatment planning

Forty years ago, almost all orthodontists viewed their role as correcting malocclusions by straightening teeth. Today, most orthodontists see their mission in the broader context of facial and dental appearances as well as the relationships of the teeth to each other. In this

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article, "dentofacial traits" is used to reflect this broader view rather than just malocclusions. Orthodontists traditionally thought of hard-tissue structural discrepancies as the major limitation of treatment. Now, however, the soft tissues are acknowledged as establishing the boundaries of dental compensation for underlying jaw discrepancies and thus more effectively determining therapeutic modifiability.^{2,3} In addition, there is greater awareness of the importance of anterior tooth display in orthodontic diagnosis and treatment.^{4,5}

In earlier efforts to consider 3D relationships, Ackerman and Proffit¹ used orthogonal projection, a 2-dimensional (2D) depiction of 3D structures. The introduction of cone-beam computed tomography (CT) now makes it possible to view the 3D relationships of both the dentition and the face directly. Models of the teeth, the traditional diagnostic record from the beginning of orthodontics, have always been used to allow a view of the relationships of the teeth from any orientation. Now it is possible to view a virtual dentition on a 2D computer screen (the traditional base used with plaster models really is not needed) while rotating the teeth to allow the same type of 3D view, and it is likely that this technology has not yet matured to its full potential. Viewing the teeth as "clouds" rather than as opaque structures offers the same type of cross-sectional block views of 3D CT. At some point, a scan directly in the mouth will eliminate impressions of the teeth to produce virtual models, and the need to mount dental casts on articulators almost surely will be supplanted.

The pace of technologic advances affecting orthodontic practice appears now, if anything, to be accelerating. Perhaps the best current example of change that opens new therapeutic possibilities is the introduction

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Fig 1. A, Airplanes can move in 3 planes (front/back, side to side, and up and down), and can also rotate around 3 axes (horizontal, axial, and vertical), thus giving pilots 6 options for changing direction of plane's motion. Movement around 3 axes is called pitch, roll, and yaw. Complete description of plane's orientation in space requires consideration of all 6 attributes. **B**, 3D analysis of orientation of the head, jaws, and dentition is incomplete without also considering 3 rotational axes of pitch, roll, and yaw in addition to planar terms anteroposterior, transverse, and vertical.

of bone anchors and screws for skeletal (absolute) anchorage; this has extended the envelope of dentofacial orthopedics. During much of the history of orthodontics, a borderline problem was one that could be treated with or without extractions. Today, borderline can also refer to a patient who could be treated either orthodontically with the aid of bone anchors or with orthognathic surgery.

Analysis of dentofacial traits

Orthodontic diagnosis to this point has focused on 3 of the 6 attributes needed to describe the position of the dentition in the face and the orientation of the head. A complete description is exactly analogous to what is necessary to describe the position of an airplane in space (Fig 1, *A*). This records movement in 3D space: translation (forward/backward, up/down, right/left), which must be combined with rotation about 3 perpendicular axes (yaw, pitch, and roll). The introduction of the rotational axes into the description of dentofacial traits (and orthodontic problems) improves significantly the precision of the description and therefore facilitates development of the problem list (Fig 1, *B*).

Because evaluation of dentofacial appearance is discussed in considerable detail elsewhere,⁶⁻⁸ it will not be elaborated on here. Suffice it to say that the clinical examination of a patient should begin with an overview of the face and the smile, followed by a closer examination of lip-tooth relationships, the perioral soft tissues, and the intraoral tissues, concluding with an evaluation of occlusal function and a detailed analysis of the static articulation of the teeth.

With 3D imaging, it is possible to visualize anatomic relationships that were heretofore impossible to discern. Attempts were made in the past to improve the thoroughness of cephalometric analysis by addng a submentovertex cephalometric image, but it was nearly impossible to identify the landmarks because of superimposed structures. The new technology allows visualization of dimensions and attributes that were indeterminate previously. Cone-beam CT can produce a 3D volumetric image in which only the structures under scrutiny are included, and all extraneous structures that would otherwise obscure the desired view can be totally excluded. Figure 2, A and B, shows 2 perspectives of an approximately 16-mm block radiographic cross-section of the maxillary and mandibular tooth crowns (8 mm above and below the occlusal plane). The block section can be examined interactively by rotating it on the computer screen in any manner around the x, y, and z axes as shown in Figure 1, B. This same approach can be applied to virtual models as shown in Figure 2, C and D.

Orientation of the head and line of occlusion

Although the importance of evaluating dentofacial traits in all 3 planes of space was emphasized previously, the orientation of the head, teeth, and jaws was not specified. Natural head position (NHP) is the most rational physiologic and anatomic orientation for evaluating the face, jaws, and teeth.⁹⁻¹¹ Thus, in our view, clinical examinations should be done with the head in NHP, cephalograms should be taken in NHP, and the orientation of 3D images should be corrected to NHP. Once NHP is established, the teeth and the jaws can be oriented to the rest of the craniofacial complex by using the occlusal plane.

The line of occlusion is used to characterize the



Fig 2. A, In-vivo submentovertex cone-beam CT view of subject with normal occlusion. Angle's line of occlusion (*red*) runs along buccal cusps and incisal edges of mandibular teeth, and along central fossae and cingulae of maxillary teeth. Perfect alignment of maxillary and mandibular lines is the condition for ideal occlusion. If patient has asymmetry characterized by rotation of maxilla, mandible, or dentition (or all of them) around vertical axis, it can be detected in this radiographic projection. Maxillomandibular yaw is often present in subdivision malocclusion. Second line (*green*), which follows facial surface of maxillary teeth and is highly visible, is esthetic line of dentition. It is particularly valuable in evaluating lip-tooth relationships and orientation of dentition relative to pitch, roll, and yaw. **B**, Cross-sectional "block" of cone-beam CT image can be manipulated on computer screen around all 3 rotational axes. Image is simply a different perspective of same image shown in *A* (images courtesy of Dolphin Imaging and Management Solutions, Chatsworth, Calif). **C** and **D**, Comparable in-vitro images to those shown in *A* and *B* produced by examining cross-sectional "block" from virtual models with same approach as described above. For certain applications, this method has the advantage of not requiring x-rays (images courtesy of OrthoCAD by Cadent, Karlstadt, NJ).

positions of the teeth in the dental arch and as a reference for assessing arch form, arch symmetry, and the curve of Spee. For nearly a century, there has been a quest in orthodontics for a suitable method of orienting the teeth to the jaws and face. Angle's concept (Fig 2, A) was that, if the buccal occlusal line of the mandibular dental arch was coincident with the line of the central fossae of the maxillary dental arch and if the teeth were well aligned, ideal occlusion would result. These lines, now conceptualized as the functional line of occlusion, are hidden from view when the maxillary and mandibular teeth are in contact.

It is important to make a distinction between the occlusal plane and the functional line of occlusion. The occlusal plane is 2D, but the line of occlusion has 3D variations because of the curve of Spee and the lack of bilateral vertical symmetry. If the upper and lower lines are misaligned (as they would be in any malocclusion),

one can describe the discrepancy between the upper and lower lines in a way that cannot be done with planes. The functional line of occlusion depicts arch form, arch width, and symmetry. It does not describe the position of the anterior teeth relative to the soft tissues of the face—ie, tooth display in the 3 planes of space and the anterior arc of the dentition (smile arc).

In modern clinical analysis, another curved line characterizing the esthetic aspect of the dentition is important in evaluating anterior tooth display (Fig 2, *B*). This line, the esthetic line of the dentition, follows the facial surfaces of the maxillary anterior and posterior teeth. We propose that the orientations of both the functional line of occlusion and the esthetic line of the dentition can best be described by using an x, y, and z coordinate system in combination with pitch, roll, and yaw (Fig 1, *B*).

From this perspective, an excessive upward or downward rotation of the esthetic line of the dentition



Fig 3. Downward or upward displacement of dentition viewed along esthetic line is best described as translation (no tilt) or pitch upward or downward anteriorly or posteriorly. **A**, Downward pitch anteriorly to point that esthetic line disappears behind lower lip with almost no incisor display; **B**, for this patient, entire maxillary dentition is displaced downward, but, on careful clinical examination, downward pitch posteriorly can be seen.

would be noted as pitch (up or down, in front or back) (Fig 3). What is now often called a transverse cant of the occlusal plane, almost always viewed relative to a skeletal relationship such as the interocular line, is more clearly visualized and described as roll of the esthetic and functional lines up or down on 1 side or the other. It is important to relate the esthetic line to the soft tissues of that area, by using the intercommissure line (Fig 4). Rotation of the line of occlusion and the esthetic line to 1 side or the other around a vertical axis is described as yaw (Fig 5). The effect of yaw is typically evident in dental or skeletal midline deviations with a unilateral Class II or Class III molar relationship. Extreme yaw is associated with asymmetric posterior crossbites, buccal on 1 side and lingual on the other. Yaw was left out of all previous classifications, including our own, because it is difficult to detect on clinical examination and was rarely visible in orthodontic diagnostic records. The availability of 3D records makes it easier to visualize the orientation of the line of occlusion now (Fig 2, B). A Fox plane can still be useful during clinical examinations in assessing pitch, yaw, and roll (Fig 6).

The orientations of the line of occlusion and the esthetic line of the dentition are important in diagnosis, treatment planning, and mechanotherapy from the standpoint of both function and appearance. Interaction of the line of occlusion and the anteroposterior vertical jaw relationships can be visualized in the Wits analysis, which is based on perpendicular lines from Points A and B to the functional line of occlusion.¹² A similar interaction of the functional and esthetic lines can be seen in the effect of Class II elastics, which tend to tip the line of occlusion down anteriorly, or in a patient with an anterior open bite and a maxillary line of occlusion that is tipped down posteriorly. With bone screws for anchorage, the maxillary molars can be intruded, thus tipping the line of occlusion up posteriorly with concomitant favorable rotation of the mandible and subsequent closure of the anterior open bite. In modern orthodontic treatment, therefore, the orientation of the line of occlusion has far-reaching significance for treatment planning and treatment mechanics.¹³

In the past, the inability to appreciate discrepancies in maxillomandibular yaw was in some ways the missing link in classification and diagnosis. When one sees a major midline shift, a unilateral Class II or Class III molar relationship, or a true unilateral crossbite, it is likely that maxillomandibular yaw exists. The extent of yaw is a major determinant in whether treatment is limited to asymmetric mechanics or might extend to asymmetric extractions, unilateral bone anchors, or surgery.

The anterior arc of the esthetic line of the dentition has been termed the smile arc,^{14,15} and the orientation and the level of the occlusal plane affect anterior tooth display during speech and smiling (Fig 5). Both the level of the occlusal plane and its pitch are important in determining the appropriate treatment for unsatisfac-



Fig 4. Rotation of esthetic line of dentition around horizontal axis, up or down on right or left side, is best described as roll. To evaluate roll relative to soft tissues, intercommissure line is best reference; to evaluate it relative to facial skeleton, interocular line is usual reference. **A**, Downward roll of dentition on right side relative to intercommissure line; **B**, roll of dentition down on right side and slightly up on left, relative to intercommisure line. There is no transverse displacement of chin, but entire right side of face is larger—interocular line rolls opposite to esthetic line of dentition. **C**, Fox plane demonstrates orientation of occlusal plane relative to interocular line, but relationship of teeth to intercommisure line cannot be seen while using it.



Fig 5. Rotation of maxilla or mandible around vertical axis of rotation leads to either dental midline shift or unilateral Class II or Class III molar relationship. Unilateral posterior crossbite accompanies more severe yaw. **A**, Yaw of maxillary dentition to left, with slight yaw of mandible in same direction. Yaw of esthetic line of dentition is greater than yaw of chin. **B**, Severe yaw of maxillary dentition to right, with almost no yaw of mandible. Patient has more elevation of right commissure on smile, so, relative to intercommissure line, she has downward roll of dentition on right. This should be noted in clinical examination, because it will be important to determine whether she considers it a problem.



Fig 6. Example of smile arc made consonant with curvature of lower lip by orthodontic treatment. Although an attractive smile arc is not a sine qua non for an attractive smile, it is recognized by many orthodontists and restorative dentists as one of the esthetic characteristics of pleasing anterior tooth display. Orthodontists can and do alter esthetic line of dentition, and this must be considered in treatment planning and biomechanics.

tory anterior tooth display. For example, the anterior teeth could be pitched too far down (or rarely, up), or the whole occlusal plane could be too far up or down, although its pitch is normal. The intercommissure line is a useful reference for evaluating anterior tooth display and lip-tooth relationships,¹⁶ and should be used in addition to the interpupillary line in the evaluation of transverse roll of the dentition. The intercommissure line and NHP are examples of orientations determined by soft tissues.

CONCLUSIONS

Because each orthodontic intervention should begin with a comprehensive evaluation of the variation in a patient's dentofacial traits, we have continued our effort to further refine orthodontic classification. In this spirit, we propose the use of pitch, roll, and yaw of the functional line of occlusion and the esthetic line of the dentition in the systematic enhancement of the Angle classification.¹⁷

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