THORAX ANGLES: A NEW METHOD OF CALCULATION

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Abbreviations

BA – breakaway
SG – Shoulder girdle
TB – top of backswing

Introduction

One issue frequently encountered in the conversations with teaching professionals is associated with different angle conventions used. This happens because in research we often use angle conventions that are different from what are commonly used in the golf community.

The attitude (orientation) of a segment (e.g. thorax) can be described by three orientation angles. Orientation angles (such as rotation, bend, and side bend) are computed as three successive rotation angles about coordinate axes from the reference attitude (global reference frame) to the attitude in question either using a Cardan sequence (each axis is used once so all axes get used: *XYZ*, *XZY*, *YZX*, *YXZ*, *ZXY*, and *ZYX*) or an Euler sequence (only two axes are used so one axis should be used twice in the first and third rotations: *XYX*, *XZX*, *YZY*, *YXY*, *ZXZ*, and *ZYZ*). Therefore, there are 12 possible ways to compute orientation angles. One problem with the orientation angle method is that different rotation sequences generate different sets of orientation angles for the same thorax attitude.

The purpose of this technical note is to highlight the issues associated with the method commonly used in the golf community (the 'popular' method) and to present a more intuitive alternative that we use in our swing analysis and research (the 'Kwon' method).

The 'Popular' Thorax Angle Convention

The popular method uses the so-called 'rotation-bend-side bend' sequence which essentially is a Cardan sequence. Let's use the thorax attitude at TB as an example (Figure 1) to explore the popular method. The arrows in Figure 1 show the directions of thorax's anatomical axes. The red arrow is the *X*-axis or the mediolateral axis (left to right). The green and blue arrows are the *Y*-axis (or anteroposterior axis) and the *Z*-axis (longitudinal axis) of the thorax, respectively. Note that The *X*-axis is not quite aligned with the shoulder line at this position due to the non-negligible SG motions (left SG protraction and right SG retraction) during the backswing.

The attitude of the thorax at this position can be described by three successive rotations from the reference attitude (laboratory reference frame) (Figure 2). In the reference attitude the *X*-, *Y*-, and *Z*-axis are aligned with the forward/backward axis, toward/away axis, and upward/downward axis, respectively. As shown in Figure 2, three successive rotations give two intermediate attitudes ($X_1Y_1Z_1$-attitude and $X_2Y_2Z_2$-attitude. Due to the way the axes are aligned with the anatomical axis, the 'rotation-bend-side bend' sequence essentially uses the *ZXY*-sequence (to be precise, ZX_1Y_2-sequence).

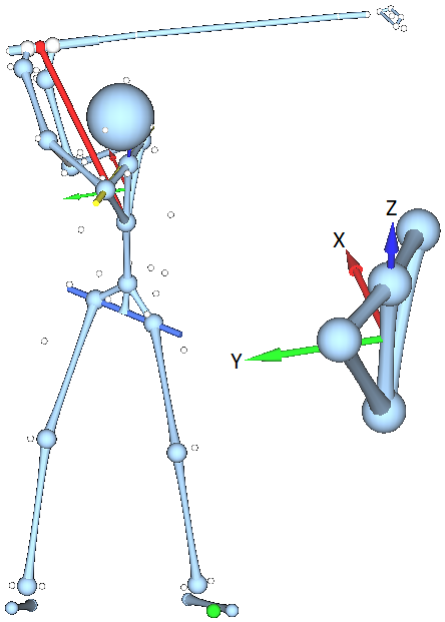

Figure 1. Thorax attitude of interest (at TB) as an example (driver). The thorax reference frame show the directions of the anatomical axes: X-axis (mediolateral axis; red arrow), Y-axis (anteroposterior axis; green arrow), and Z-axis (longitudinal axis; blue arrow).

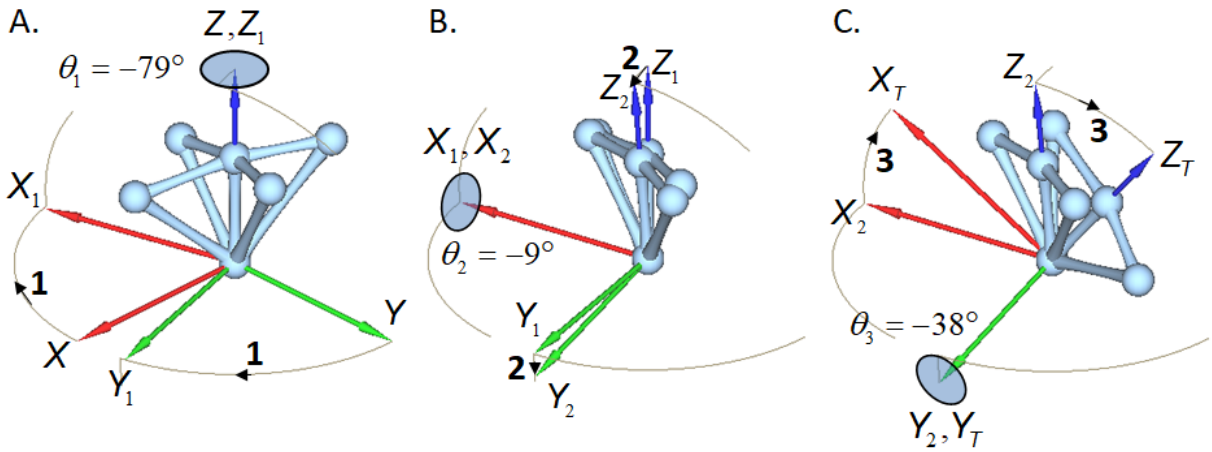

Figure 2. Orientation angle decomposition using the 'rotation-bend-side bend' sequence. The first rotation is about the *Z*-axis of the reference attitude (A). The second rotation is about the temporary X_1-axis (bend axis; B), and the third rotation is about the temporary Y_2-axis (side bend axis; C).

The first rotation is about the *Z*-axis (vertical axis) of the reference attitude and this is the 'rotation' axis. The second rotation is about the new *X*-axis after the first rotation (X_1-axis), the 'bend' axis. The third rotation is about the new *Y*-axis after the second rotation (Y_2-axis), the 'side bend' axis. The orientation angles of the thorax at TB in this sequence are [-79°, -9°, -38°] and can be interpreted as 79° right-rotated, 9° forward-bent, and 38° left-bent.

The 'Kwon' Convention

The angle convention we use in our analysis of thorax motion is the so-called 'azimuth-lean-rotation' sequence. As shown in Figure 3, the spine axis (longitudinal axis of the thorax) and the spine plane

(vertical plane that contains the spine axis) play a key role in angle computation in this convention. The first angle computed in this method is the 'azimuth' angle (lean direction angle) which is the angle formed by the spine plane and the forward axis on the horizontal plane. The second angle computed is the 'lean' angle which is defined on the spine plane. The third angle is the 'rotation' angle measured on the plane perpendicular to the spine axis about the spine axis.

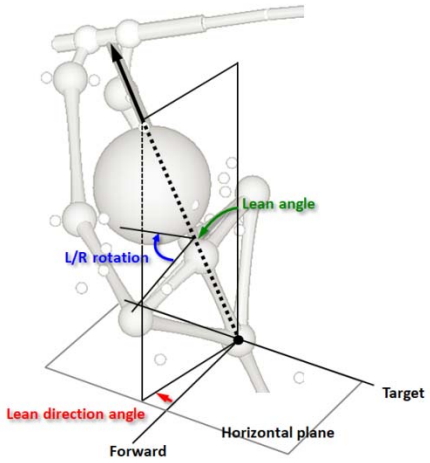

Figure 3. The 'azimuth-lean-rotation' sequence. In this method, the spine axis (arrow drawn from the mid-trunk point to the mid-shoulder point) plays a key role in identifying the orientation of the thorax. Firstly, the spine plane (the vertical plane that contains the spine axis) is used in computing the azimuth (lean direction) angle: toward or away. The second angle to be identified is the lean angle measured on the spine plane. The third angle is the rotation angle measured in the plane perpendicular to the spine axis.

Figure 4 shows the decomposed orientation angles of the same thorax attitude presented in Figure 1 but using the Kwon sequence. The first rotation is about the *Z*-axis of the reference attitude: azimuth angle. The second rotation is about the new *X*-axis after the first rotation (X_1-axis), the lean axis. The third rotation is about the new *Z*-axis after the second rotation (Z_2-axis), the rotation axis. In this rotation sequence, the 'rotation' angle was assessed about the spine axis (longitudinal axis of the thorax), not about the vertical axis (global *X*-axis). The 'azimuth-lean-rotation' sequence is equivalent to the *ZXZ*-sequence (to be precise, ZX_1Z_2-sequence) of the Euler sequence family. The orientation angles of the thorax at TB in this sequence are [3°, -38°, -76°] or 3° toward the target, 38° down, and 76° right-rotated.

So Which One Is More Meaningful?

The orientation angles computed using the two sequences introduced above are somewhat different but not too much in this particular position: [-79°, -9°, -38°] in the popular method vs. [3°, -38°, -76°] in the Kwon method. This is because the posture at TB is close to 90° right rotation with 0° forward bend. So the side bend plane is close to the spine plane in this case and the side bend angle should be similar to the lean angle (38°). The angles, however, can be quite different for an attitude mid-way between BA and TB, shown in Figure 5: [-43°, -27°, -26°] in the popular method vs. [3°, -37°, -40°] in the Kwon method. Both the forward bend and side bend angles are quite different from those at TB in the popular method. In Kwon method, however, the azimuth and lean angles are quite similar to those observed at TB. Considering the fact that the angular motion of the thorax during the backswing is close to a simple axial rotation about the spine axis with minimal precession of the spine axis, the values reported by the Kwon method for the two different attitudes make sense.

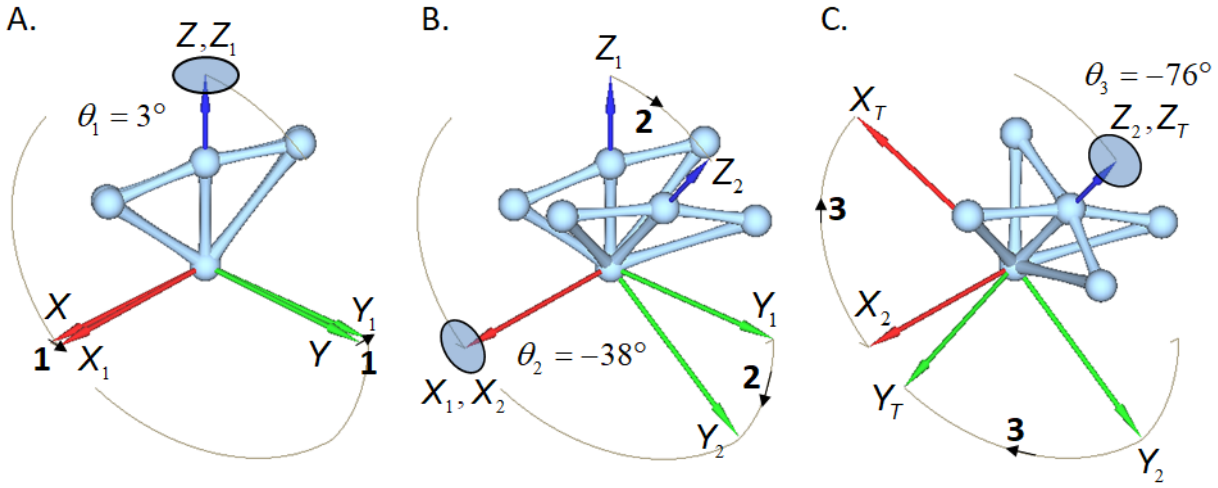

Figure 4. Decomposition of the orientation of the thorax using the 'lean direction-lean-rotation' sequence. The first rotation is about the *Z*-axis of the reference attitude (A). The second rotation is about the temporary X_1-axis (lean axis; B), and the third rotation is about the temporary Z_2-axis (rotation axis; C).

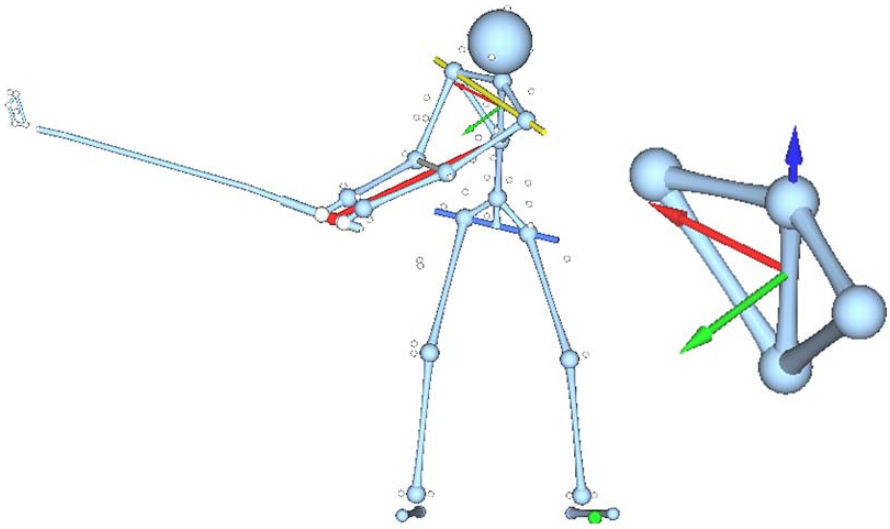

Figure 5. A sample thorax attitude mid-way to TB (driver). The rotation angle is close to 40° here.

One important criterion that should be considered in rotation sequence selection is 'intuitiveness' of the angles. In other words, golfers should be able to intuitively figure out the orientation angles of a given attitude with reasonable accuracy without elaboration. Likewise, golfers also should be able to reach the prescribed attitude with reasonable accuracy without elaboration for a given set of orientation angles. Intuitiveness in the Kwon method mainly comes from the fact that the first two angles are assigned to the attitude of the main axis of the segment in question (the spine axis in the case of thorax). The third rotation, therefore, is about the main axis. It is intuitively easier to bring the main axis to the prescribed attitude using the first two angles and then add the rotation about the main axis using the third rotation. The order of the first two angles can also be determined based on the intuitiveness and meaningfulness of the resulting angles.

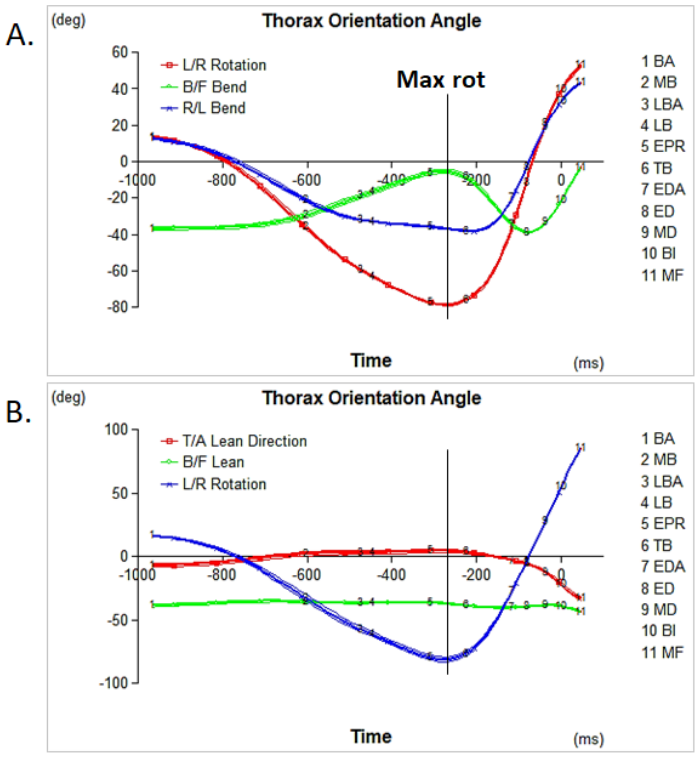

Figure 6. Angle-time plots of the thorax orientation angles (driver, PGA Tour-caliber player): the popular method (A) and the Kwon method (B). Note that all three angles change substantially during the backswing and early phase of the downswing in the popular method while the azimuth (lean direction) angle and the lean angle are fairly maintained in the Kwon method.

It will be safe to say golfers mainly rotate the thorax about the spine axis during the backswing and early phase of downswing with minimal precession of the spine axis. This is evident in the angle-time plots (Figure 6). During the backswing, the popular method (Figure 6A) shows large ranges of all three angles: 92° rotation range (14° left to 78° right), 32° bend range (37° forward to 5° forward), and 50° side bend range (13° right to 37° left). The Kwon method (Figure 6B), however, shows a lot smaller azimuth (lean direction) and lean angle ranges: 11° azimuth range (7° away to 4° toward), 4° lean range (39° forward to 35° forward), and 97° rotation range (16° left to 81° right). This golfer (PGA Tour-caliber player) maintains the thorax lean angle fairly constant throughout the swing (driver).

This aspect is particularly meaningful in biofeedback. In bringing the thorax to a prescribed attitude, it should be easier to align the spine axis first using the first two angles and then rotate the thorax about the spine axis to the prescribed attitude. In other words, with reasonably set lean direction and lean angle ranges, the prescribed spine axis attitude can be reached in the setup position at BA already and subsequent efforts can just be directed to reaching the prescribed rotation position (the Kwon method). In the popular method, however, all three angles change simultaneously as the golfer continues the simple axial rotation of the thorax about the spine axis in the backswing. It is hard to control all three angles simultaneously to reach the prescribed position. This should be a fairly well-known issue to anyone with reasonable experiences with the biofeedback functions available in the electromagnetic sensor-based or inertial sensor-based systems.

Summary

There are 12 possible rotation sequences (six Cardan and 6 Euler sequences) that can be used in computing the orientation angles of a segment such as thorax and the problem is that different rotation sequences yield different orientation angle values. Therefore, it is important to select a practical and meaningful rotation sequence. One key aspect that must be considered in rotation sequence selection is intuitiveness of the orientation angles reported. Intuitiveness mainly comes from whether the golfer can figure out the orientation angles of a given attitude or reach a prescribed attitude with reasonable accuracy without elaboration. The 'Kwon' method presented in this technical note appears to be superior to the currently used 'popular' method in the perspective of intuitiveness in general and usefulness in biofeedback in particular.

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