Title. “Variability in gait analysis comes more from the axis definition than movement itself”

**Introduction**.

In clinical gait analysis, kinematic data relative to joint motion is computed by evaluating the continuous movement of one segment with respect to its adjacent. This motion have been typically expressed using two mathematical methods: the Euler sequence (ref Chao 1980) and the attitude vector/helical axis/screw axis (Woltring, 1991). The Euler sequence represents the overall joint movement through a set of three rotations about the sagittal, transversal and coronal plane. Due to its easy interpretability it is the gold standard (recommended by the ISB (Wu & Cavanagh, 1995)) method to express joint motion in clinical practise. However, the decomposition of the overall movement into three rotations are known to be prone to error propagation (Ge Wu, 2002) and subject to the effect of cross-talk (Pothrat et al., 2015). Moreover, magnitudes of movement represent by the three Euler angles method are dependent on the sequence of rotations (Chéze, 2000). On the other hand, helical axis provides a unique description of the motion as a rotation about combined with a translation along it. Helical axis is less sensitive to error but it has low interpretability in clinical practice.

Current reproducibility in clinical gait analysis is generally accepted among the clinical community. However, some variability due to measurement error and intrinsic factors of the patient are observed (ref). This variability can impact the interpretation of the results (ref). Variability arise from three factors: 1) Definition of the axis of the each lower limb segment; 2) movement pattern variation among multiple trials; and 3) Definition of the axis of rotation (Euler angles). The uncertainty in placing the markers over the anatomical landmarks and soft tissue artefacts are the main causes of inaccuracy defining the joint centres and the axis of the segments. Movement pattern variation is caused by the capability of the subjects to repeat the same gait patterns (movement) across trials which is also enhanced by the presence of motor disorders (ref).

We hypothesise that the variability in gait analysis is more dependent on the axis definition than the movement itself. Thus, the aim of this study is to compare the variability of gait analysis expressed into a single helical axis and joint motion expressed into a set of three Euler rotations.

Variability in gait analysis may come from the three axis of rotation (Euler angles), movement and axis definition.

Literature

Objective. Thus, the objective of this study is to compare the variability of kinematic data expressed as helical axis and Euler angles.

**Methods**.

Data Collection

Testing Procedure.

**Evaluation of variability among both methods to describe joint motion**

1. The joint kinematics of the data is computed
2. Extract rotation matrix from Euler angles.
3. Extract k (attitude vector) and theta (helical angle)
4. Calculate mean of k among all frames.
5. Compute angle between mean k and instant k, (then normed)
6. Dot product mean k and instaneous k.
7. Inverse cos = theta (helical angle)
8. Project ktheta into 3 Euler sequence
9. Calculate variability of Euler angles, projected ktheta into euler angles, helical axis and variation of helical axis. (RMSD)

**Relationship between the parameters (theoretical concept) to understand the propagation of uncertainty.**

Statistical Analysis

**Results**.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Inter-Session (Geneve) – RMSD°** | | | | | | | | |
| Row | Helical Angle | Variation Helical Axis | Euler x | Projected KTheta x | Euler y | Projected KTheta y | Euler z | Projected KTheta z |
| Hip | 3.79 | 20.72 | 4.38 | 4.53 | 1.55 | 1.97 | 4.38 | 4.28 |
| Knee | 3.12 | 6.35 | 5.06 | 5.05 | 2.21 | 2.87 | 4.77 | 4.58 |
| Ankle | 3.36 | 12.63 | 4.85 | 4.98 | 5.02 | 4.99 | 4.61 | 4.48 |
|  |  |  |  |  |  |  |  |  |
| Inter –Session (Montreal)**– RMSD°** | | | | | | | | |
| Hip | 2.64 | 13.22 | 1.78 | 1.69 | 1.34 | 1.84 | 4.99 | 4.88 |
| Knee | 4.39 | 5.19 | 4.20 | 4.22 | 2.63 | 5.38 | 9.28 | 8.33 |
| Ankle | 3.54 | 15.00 | 3.55 | 3.69 | 3.45 | 3.95 | 6.77 | 6.57 |
|  |  |  |  |  |  |  |  |  |
| Intra-Session (Geneve)**– RMSD°** | | | | | | | | |
| Hip | 1.44 | 3.01 | 1.49 | 1.50 | 0.74 | 0.89 | 1.43 | 1.37 |
| Knee | 1.99 | 3.01 | 2.36 | 2.34 | 0.59 | 0.85 | 1.58 | 1.50 |
| Ankle | 2.02 | 9.06 | 2.12 | 2.17 | 1.73 | 1.73 | 2.25 | 2.24 |

Result 1. Variability helical angle < Euler angles (for most of the joint angles)

Result 2. Variability of Euler angles and projected ktheta very similar.

Result 3. Variability between session > within session.

Result 4. Variation Helical axis ??

Result 5. Better reproducibility Montreal data for ext/flex and add/abd but better in Geneva data for rotation.

**Discussion**.

Evaluating how the variability propagates is important to understand why some of the angles are, for instance, more uncertain than others.

**Conclusion**.