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Journal of Biomechanics 36 (2003) 300–302

JOURNAL OF BIOMECHANICS

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Letter to the editor

## ISB recommendation on definition of joint coordinate systems for the reporting of human joint motion—part I: ankle, hip and spine

Can I first congratulate the authors of this article (Wu et al., 2002) for the considerable effort that must have gone in to drawing up these proposals. Can I also apologise to them for my joining the debate at this stage rather than participating earlier in the process when the hard work was being done. One of the aims laid out in the abstract is to "stimulate feedback and discussion, and to facilitate further revisions" and I hope this contribution will be seen as a response to that invitation.

The authors state in their Introduction that the use of the Grood and Suntay (1983) convention (GSC) "makes the application and interpretation of biomechanical findings easier and more welcoming to clinicians". The main problem I have with the recommendations is that the precise implementation of the GSC for the different joints gives joint angle definitions that are not consistent with conventional clinical usage. I also have some criticisms of other elements of the proposal which I have outlined after this primary issue.

### Joint rotations

There is much misunderstanding of the GSC for describing the orientation of one co-ordinate system (CS) with respect to another. Chao (1980) in an early and elegant article established that the GSC is simply another way of picturing a particular sequence of Cardan angle rotations. Cardan angles are well known to be sequence dependent. The equivalence of this for the GSC is that the angles are dependent on which axis is specified as fixed in the proximal segment and which in the distal segment. In implementing the GSC for joints other than the knee, for which it was originally described, it is necessary to separate its principles (that rotations can be viewed as about a fixed axis in the proximal segment, then a floating axis, then one fixed in the distal segment) from their application to a particular joint (the choice of which fixed axes to choose). I am in full agreement with the authors that the principles of the GSC can be applied to all the joints described but contend that the choice of which axes to choose must differ from joint to joint. This is because, while all possible choices of axes result in mathematically consistent results, only one choice of angles for each joint gives results that can be reconciled with conventional clinical terminology. Even this approach depends on some ambiguity in the exact meaning of the clinical terms. This allows a little flexibility in a formalization of these terms which is consistent with conventional usage but also mathematically rigorous. I have established this for the orientation of the pelvis with respect to a fixed external CS elsewhere (Baker, 2001) but the reasoning can be extended to the other joints.

The first rotation is about an axis fixed in the proximal segment. It can equally well be thought of as a rotation in a plane perpendicular to that axis (the sagittal plane in the case of the knee). The advantage of this is that, as the second axis is perpendicular to the first, it must lie within this plane. Thus whereas the first rotation is a rotation within the plane, the second is a rotation out of the plane. The final rotation is about the axis fixed in the distal segment. Grood and Suntay (1983) defined their convention for the knee and their choices of fixed and floating axes are consistent with the conventional clinical definitions which if formalized can be stated as:

> *Flexion/extension* is a rotation in the sagittal plane of the femur.
> *Ab/adduction* is a rotation out of the sagittal plane of the femur.
> *Internal* or *external rotation* is about the long axis of the tibia.

It should be noted here that modern anatomical terminology tends to define ab/adduction as a rotation away from the mid-line rather than out of the sagittal plane but this definition cannot be used as the basis for a mathematically rigorous definition of three dimensional joint angles. The above definition is felt to be close enough to conventional clinical usage but can be used with mathematical rigour. The clinical terminology for the hip is consistent with that for the knee so the GSC can be applied directly to the hip as the authors have done.

In considering the correct implementation of the GSC for other joints it is perhaps easiest to recognise that only one rotation, the last, is about an axis fixed in the distal segment. Thus if conventional clinical terminology defines one rotation as occurring about an axis in the distal segment then this must be the last in the GSC. For

0021-9290/03/$ - see front matter 
PII: S0021-9290(02)00336-6

the hip and knee this is internal rotation, which is conventionally a rotation about the long axis of the distal segment. For the ankle joint complex it is inversion–eversion, the rotation about the long axis of the foot. This must therefore be the third axis of the GSC. The authors, however, have chosen to define it as the second rotation, about a floating axis which is generally not coincident with the long axis of the foot. The mathematics is internally consistent but the results don't correlate with a clinician's understanding of the terms. To be consistent with clinical terminology the following definitions are preferable:

$e_1$ The $z$-axis (medio-lateral) fixed in the tibia,
$e_3$ The $x$-axis (longitudinal) fixed in the calcaneus,
$e_2$ The floating axis mutually perpendicular to $e_1$ and $e_3$.

$e_1$ thus represents rotation within the sagittal plane of the tibia and $e_2$ the rotation out of this plane. If this biomechanical convention is adopted then the formalized clinical definition of terms is:

*Dorsiflexion/plantarflexion* is a rotation in the sagittal plane of the tibia.
*Ab/adduction* is rotation out of the sagittal plane of the tibia.
*Inversion/eversion* is about the long axis of the calcaneus.

My work on the pelvis (Baker, 2001) was described in terms of Cardan angles but Chao's (1980) work allows the underlying reasoning to be reformulated in terms of the GSC. In the axial skeleton the sagittal plane is a plane of symmetry and it is the rotation about the axis perpendicular to this, the medio-lateral axis, which is best considered as the rotation fixed in the distal segment. As above, this must be the last rotation in the GSC. Axial rotation describes where this axis is within the horizontal plane and obliquity the rotation out of the horizontal plane. The formalized definitions of clinical terms are then:

*Axial rotation* is the angle in the horizontal plane by which one point on the segment is in front of its mirror image.
*Obliquity* is the angle out of the horizontal plane by which one point is higher than its mirror image.
*Tilt* is the angle through which the pelvis has been rotated about its medio-lateral axis.

Although these are couched in the terms that I am familiar with as a gait analyst for describing the pelvis in relation to the laboratory CS they are equally applicable to the multitude of similar terms used to describe similar movements of the axial skeleton. They can also be directly generalized to describe the relationship of one axial skeleton CS to another. In order to be consistent with this terminology the Grood and Suntay axes must then be defined as

$e_1$ The $y$-axis (proximal–distal) fixed in the reference segment,
$e_3$ The $z$-axis (medio-lateral) in the moving segment,
$e_2$ The floating axis mutually perpendicular to $e_1$ and $e_3$.

This is different from the convention suggested by the authors. I have used the terms reference and moving segment here because for the spine there may be some ambiguity as to whether it is the movement of the proximal vertebrae with respect to the distal or vice versa.

It is tempting to try and impose consistency on the GSC by assuming that it is always the $z$-axis that is fixed in the proximal axis system and the $y$-axis in the distal system but the above reasoning suggests that to be consistent with the established clinical terminology the fixed axes have to be chosen carefully and differently for each joint. Much of the value of biomechanics is in the insight it can give to the clinical community. By adopting the conventions proposed in the ISB's name which are not consistent with conventional clinical descriptions of joint angles a barrier is being built between biomechanists and clinicians.

## Tibia

The tibia/fibula is the only segment for which a definition of the standard anatomical planes has been proposed. It would be nice to see these for the other segments but what is more concerning is that the axes of the proposed co-ordinate system (CS) are not aligned with these planes. Because the inter-malleolar axis is defined first, the proximal–distal axis of this segment is oblique to its long axis. This means that angle definitions are not consistent with standard clinical terms and also that the definition of the tibia for the purposes of the ankle joint is one which cannot possibly be used as a basis for describing knee movement (the proximal distal axis does not pass through, or even close to, the knee joint center, see Fig. 1 in the original article). I fully appreciate the need to define proximal and distal CS for the tibia to account for tibial torsion, as in the definition of anatomical planes, but feel they should share a common long axis.

## Joint translations

The inclusion of the definition of axes for joint translation within the definition of the axes for joint rotation may lead to some ambiguity. It might be inferred from this that the translations are along the joint rotation axes. These axes are not orthogonal and this clearly does not make sense. I assume the authors intend that the translations are measured in the orthogonal axis system of the reference segment.

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