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Annotation

Foot models for clinical gait analysis

The last few years have seen the publication of a plethora of foot models [1–11]. This edition of Gait and Posture contains two more [12,13]. These represent models that have attracted considerable attention when presented at conferences over the last few years and are now available for us to peruse in detail. The first paper describes the modification of the Oxford foot model for paediatric use and the second the Heidelberg foot measurement method (HFMM). Some of the earlier published models did not contain sufficient detail to allow other users to repeat the work. Following a pattern established in a number of more recent papers, both of these are exemplary on this account.

There seems to be a consensus emerging that the foot can be modelled as a small number of segments and that the angular relationships between these are best expressed as Euler angles. Most investigators use three segments, one of which is the hallux. The only published exception, from Utah [5], proposes the use of eight segments. All recent work is based on skin-mounted markers with the exception of the group in Bologna [4]. This is in keeping with developments in kinematic modelling in other regions of the body. The Oxford model would appear to incorporate most aspects of this developing consensus.

The HFMM differs from this consensus in that there is no formal definition of segments and Euler angles are not used. A new concept for describing joint angles is developed which requires the specification of two lines and an axis of rotation. The joint angle is that between the projections of the two lines onto the plane perpendicular to this axis. The markers used to derive these lines are not constrained to be on adjacent segments. These angles are derived to correspond to common radiological measurements and might therefore be more immediately comprehensible to clinicians than those produced by the conventional segment based approach. This conventional approach, however, embodies a conceptual understanding of how the foot functions in terms of the segments and how they move in relation to one another. Whilst approaches like the HFMM offer an effective means of describing foot deformities, it may be that segment based models are more inherently suited to explain the underlying biomechanical mechanisms.

Reporting of measurement variability in kinematic models is improving generally and both papers report such variability in terms of ''standard deviations'', which have the advantage of being in the same units as the measurements themselves. This makes it much easier to assess the clinical implications of measurement variability. The data look encouraging although it is necessary to remember that a range of four times the standard deviation might be a better indicator of the total range of measurement variability. Both papers give excellent representation of normative values. Whilst clear patterns emerge it is again necessary to remember that 35% of normal data will fall outside the ± 1 standard deviation bands used to display the normal range in both papers.

Thus the current state of the art is that several foot models have been published in sufficient detail to allow them to be implemented by others and whose performance in terms of reliability is well documented. The proof of whether these are clinically useful will only come through such implementation. Publications are now appearing [11,14–17] that relate the use of different foot models in various clinical populations. These are essential to determine which of the available approaches are the most clinically useful. It is hoped that the methods appearing in this issue of Gait and Posture will be used in future studies to establish their place in clinical practice.

Foot models have traditionally been seen as separate to models of the lower limb or the full body. Until recently the requirement to detect multiple markers accurately on the foot has required a different camera set-up to that used to capture the more proximal joints. Modern gait analysis instrumentation is now capable of detecting multiple small markers on the foot as well as those on the rest of the body. Clinicians should be able to look forward to obtain integrated kinematic models of the foot and lower limbs as being part of a standard gait analysis package in the near future.

General kinematic modelling is moving away from deterministic models towards models based on an optimised fit of the underlying model to experimental data [18–20]. Such techniques have been advocated for distinguishing

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talo-crural from sub-talar joint movements for many years [10]. More recently a lower limb model incorporating these two joints specifically has been reported [20]. It will be interesting to see what such optimisation techniques have to offer to the modelling of the more distal joints within the foot.

The development of models to include kinetics of the intrinsic joints of the foot may be more problematic. Such a model [5] has been reported that combines information from a pedobarograph and a force plate with a multi-segment kinematic model to compute joint moments and powers. Whilst this pioneering work is encouraging, it requires combination of instrumentation that is not available in most clinical labs and is based on some assumptions which require more critical evaluation before routine clinical implementation can be considered.

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