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Quantitative comparison of five current protocols in gait analysis

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Abstract

Data collection and reduction procedures, coherently structured in protocols, are necessary in gait analysis to make kinematic and kinetic measurements clinically comprehensible. The current protocols differ considerably for the marker-set and for the biomechanical model implemented. Nevertheless, conventional gait variables are compared without full awareness of these differences.

A comparison was made of five worldwide representative protocols by analysing kinematics and kinetics of the trunk, pelvis and lower limbs exactly over the same gait cycles. A single comprehensive arrangement of markers was defined by merging the corresponding five marker-sets. This resulted in 60 markers to be positioned either on the skin or on wands, and in 16 anatomical landmark calibrations to be performed with an instrumented pointer. Two healthy subjects and one patient who had a special two degrees of freedom knee prosthesis implanted were analysed. Data from up-right posture and at least three gait repetitions were collected. Five corresponding experts participated in the data collection and analysed independently the data according to their own procedures.

All five protocols showed good intra-protocol repeatability. Joint flexion/extension showed good correlations and a small bias among protocols. Out-of-sagittal plane rotations revealed worse correlations, and in particular knee abduction/adduction had opposite trends. Joint moments compared well, despite the very different methods implemented. The abduction/adduction at the prosthetic knee, which was fully restrained, revealed an erroneous rotation as large as 30° in one protocol. Higher correlations were observed between the protocols with similar biomechanical models, whereas little influence seems to be ascribed to the marker-set.

Keywords: Gait analysis; Inter-protocol repeatability; Kinematics; Kinetics; Data reduction

1. Introduction

Protocols of gait analysis are intended to make kinematics and kinetics of pelvis and lower limbs clinically interpretable [1–4]. A protocol defines a biomechanical model and the procedures for data collection, processing, analysis and reporting of the results. Historically, probably because of the constraints implied in the pioneering technology, only few laboratories have developed their own protocol independently according to specific clinical requirements [5]. In addition to the different marker-sets and collection procedures, many important differences exist between the current protocols also in the biomechanical model, which includes the measured variables, degrees of freedom assigned to the joints, anatomical and technical references, joint rotation conventions and terminology. In spite of these differences, gait analysis data are shared, exchanged and interpreted irrespectively of the protocol adopted. Recent international initiatives in clinical gait analysis, such as web-accessible services for data repository

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Intra-protocol variability was small for all five protocols. This implies that intra-subject repeatability over the trials, however small in the three subjects analysed, was reported consistently over the protocols. In addition, the comparison of values in Tables 1 and 2 shows that inter-protocol variability is clearly larger than intra-protocol variability, except for pelvis rotation.

Overall the gait variables are comparable among protocols (Fig. 3), despite the large differences between models and marker-sets. Joint kinematics showed larger inter-protocol differences than joint kinetics. Flexion/extension had good waveform correlations with small bias differences in all joints except the ankle. On the contrary, out-of-sagittal plane rotations, especially at the knee and ankle joints, revealed poor waveform correlations and even considerable bias differences. The largest variability was observed at knee abduction/adduction where even opposite trends were observed. The extent to which this is due to the different models, marker-set or to relevant skin artefact is not known. Because similar patterns were observed over the six knees, it is hypothesized that a bias associated to the axis of rotation and related cross-talk is more plausible than an erroneous positioning of the markers.

The large consistency observed for the joint moments is noteworthy because of the known substantial differences between protocols about this calculation. LAMB, SAFLo and PiG use standard inverse dynamics, whereas T3Dg and CAST use only the external ground reaction force. Estimation of the joint centres is also very critical, and each protocol uses different techniques. This acceptable coherence on the results may further support the role of the external force, which must be predominant in gait at natural speed.

The PiG, based on the original Newington model, and SAFLo are among the pioneering protocols for gait analysis. When these were devised, basic instrumentation and limited knowledge of the skin artefacts were available. Therefore, it is remarkable that these protocols have obtained adequate correlation with the more recent ones for most of the gait variables. Bias and correlation differences of SAFLo are straightforwardly accounted for the specific anatomical references particularly for the pelvis and the ankle. T3Dg is a recent development of the general CAST approach. The very similar relevant results support further the fact that a small deterioration of the results is expected when the location of markers in the central area of the segments and calibration of landmarks via an instrumented pointer are substituted with direct skin marker placement. T3Dg and LAMB protocols share most model definitions except the equations for hip joint centre estimation (according to Refs. [35] and [8], respectively). Slightly different choices are adopted also for the marker-set, but all this did not result in considerable final differences for the gait variables. Overall, the high correlation obtained for the variables calculated by CAST, LAMB and T3Dg (Table 4) suggests that a large uniformity of the results is associated more to the consistency of the biomechanical conventions than to the design of the relevant marker-sets.

The abduction/adduction of the right knee of subject SZM (Fig. 5 and Table 3), i.e. the gold standard, revealed a considerably different performance of PiG with respect to the other protocols, though limited to the first half of the swing phase. This might have been due to an incorrect marker location resulting in incorrect alignment of the axis of rotation and therefore in cross-talk from flexion/extension, relatively large in that phase, to abduction/adduction. However, most of these markers are shared by the other protocols. In addition, a predisposition to larger abductions at the knee for this protocol was reported for all six knees. A larger variability for the joint rotations that require careful alignment of the wands was reported for this protocol also elsewhere [5,30]. The best performance in assessing this gold standard was obtained by SAFLo. This protocol identifies the flexion axis of the knee with a functional approach [36], which is expected to reduce this cross-talk.

The above remarks are only preliminary accounts of the observed differences. A thorough and rational comparison of the five techniques is possible by looking at every single gait variable and by inferring relevant justifications for these. The task is however not easy because the time-history of each variable results from an intrigued interplay of reference definitions, kinematics conventions and artefactual motion.

In conclusion, the comparison of the results from the five protocols on the same gait cycles revealed first of all good intra-protocol repeatability. Despite the known large differences among the techniques, good correlations were observed for most of the gait variables. As for the exact variable patterns, good consistency was found for all joint flexion/extensions and pelvic rotations. Acceptable consistency was found for hip out-of-sagittal plane rotations and nearly all joint moments, whereas it was poor in knee and ankle out-of-sagittal plane rotations. For the latter therefore, it is recommended that comparison of the results among protocols be very careful. The variability associated to the protocol used seems much larger than that associated to inter-observer and even inter-laboratory comparisons [5,17,29,30] for most of the gait variables. It might be also pointed out that, in general, model conventions and definitions seem more crucial than the design of the relevant marker-sets, and that therefore sharing the former can be sufficient for worldwide clinical gait analysis data comparison.

Conflict of interest statement

The author states that there is no conflict of interests for the manuscript.

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