What Is The Level of Validation Of Multibody Optimisation For The Estimation Of Human Joint Kinematics? A Review

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WHAT IS THE LEVEL OF VALIDATION OF MULTIBODY OPTIMISATION FOR THE ESTIMATION HUMAN JOINT KINEMATICS? A REVIEW

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Introduction

Multibody optimisation is increasingly used to estimate human joint kinematics from stereophotogrammetry or other emerging motion analysis systems. The method is alternatively called global optimisation, inverse kinematics or motion reconstruction in different research fields.

Multibody optimisation is a key step in musculoskeletal modelling but is also commonly used for kinematics and dynamics analysis with the aim of compensating for the soft tissue artefact. Nevertheless, the level of validation of the multibody optimisation is not well established.

A review of the literature was performed in order to answer this question.

Methods

An electronic search was performed (in January 2016) in Embase, Medline, Scopus, PubMed, and Web of Science. Logical expressions for the search included “optim* or kalman”, “kinemat* joint”, “subject or human or limb”, and “model* or over*determ*”. The search was based on the title, keywords and abstract. Reference list of key studies were also cross-referenced to obtain further articles.

The articles retrieved from the search strategy were reviewed according to the following exclusion criteria: non English language, conference proceeding, single body or under-constrained optimisation, no kinematics results reported, predictive simulation, markerless, sensorless or single-camera motion analysis, application in cadaveric specimens, animal, robots and machines. Studies focussing on spine, hand, foot and mandible were also excluded.

Results

The search results were Embase: 738, Medline: 729, Scopus: 721, PubMed: 169, Web of Science: 417. After removing duplicates, the number of articles was 1441. According to the exclusion criteria, 53 articles were selected from the search, 8 more articles were obtained by cross-referencing and 5 very recent articles known by the authors were finally added.

In the 66 articles analysed, only 8 reported validation of the optimised kinematics against reference data (i.e., intra-cortical pins, fluoroscopy, radiography, and manual palpation in case of the scapula). Some authors used simulated data as reference (i.e., 9 articles) or performed sensitivity analysis (i.e., 5 articles). Most of the studies analysed the residuals errors on the marker positions (i.e., 15 articles) or compared the kinematics obtained with and without optimisation or obtained with different optimisation methods (i.e., 29 articles).

Moreover, few studies evaluate the performance of multibody optimisation on pathologic subjects except 6 articles on knee osteoarthritis [1], knee ligament deficiency [2-3], knee prosthesis [4-5], and cerebral palsy [6].

When validated against reference data (on asymptomatic subjects), the typical errors for the model-based tibiofemoral rotations were between 1° and 22° during squat, gait and running movements and the errors were maximal for internal-external rotation [1, 7-8]. Typical errors for the model-based scapula-thoracic rotations were between 3° and 10° during arm flexion and abduction and the errors were maximal for internal-external rotation [9-10].

Discussion

This review demonstrates that the level of validation of multibody optimisation for the lower and upper limb remains limited.

The validations against gold standard are scarce due to the experimental difficulties to obtain intra-cortical pins and fluoroscopic data. The simulated data used for validation includes unrealistic soft tissue artefact models. The residual errors on the marker position cannot be considered as a validation but rather as an evaluation of the model ability to simulate the gross motion. It may be used, together with sensitivity analysis and comparison of different optimisation methods, to globally assess the model degrees-of-freedom and geometry. The comparison of the kinematics obtained with and without optimisation has a limited impact since none of them can represent the actual bone kinematics.

Nevertheless, the most accurate and validated results of multibody optimisation are rather encouraging for application in clinical, ergonomic and sport movement analysis.

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