Gait & Posture xxx (2009) xxx–xxx

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Review

Quantification of soft tissue artifact in lower limb human motion analysis: A systematic review

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ARTICLE INFO

Article history:
Received 5 December 2008
Received in revised form 28 August 2009
Accepted 12 September 2009

Keywords:
Soft tissue artifact
Lower limb
Motion analysis
Error

ABSTRACT

This systematic review critically evaluates the quantification of soft tissue artifact (STA) in lower limb human motion analysis. It has a specific focus on assessing the quality of previous studies and comparing quantitative results. A specific search strategy identified 20 published articles or abstracts that fulfilled the selection criteria. The quality of the articles was evaluated using a customised critical appraisal tool. Data extraction tools were used to identify key aspects reported in the articles. Most studies had small sample sizes of mostly young, slim participants. Eleven of the reviewed articles used physically invasive techniques to assess STA. STA was found to reach magnitudes of greater than 30 mm on the thigh segment, and up to 15 mm on the tibia. The range of soft tissue artifact reached greater than 25 mm in some cases when comparing the results of reviewed studies.

1. Introduction

Stereophotogrammetry [1] is the most frequently used method of clinical human motion analysis [2]. Due to inaccuracies related to working with biological systems [3], there are limitations in the way 3D motion data are acquired. Markers attached to the skin move with respect to the underlying bones that they are intended to represent [4]. This error is known as "soft tissue artifact" (STA).

STA arises from movement or deformation of the subcutaneous tissues associated with muscular contractions, skin movement and inertial effects [5]. The extent of STA for any movement depends upon the physical characteristics of individuals [6], marker locations [7] and the nature of the movement task being performed [8]. The exact magnitude of STA in kinematic calculations has been difficult to determine. Leardini et al. [3] summarised the different methods used to assess and compensate for STA. Here, we provide a systematic review and critical evaluation of the published literature on methods to quantify STA. The review will analyse the quality of the available literature and aim to summarise assessment techniques used to quantify the effects of STA on kinematic results. Furthermore, the review identifies what is known about STA in current motion analysis practice.

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doi:10.1016/j.gaitpost.2009.09.004

2. Methods

2.1. Search strategy

An electronic search of the following international databases was performed in November 2008; MEDLINE (1950), Embase (1980), Cinahl (1982), Web of Science (1900), Biosis (1969) and Inspec (1898). Keywords in the search strategy included 'minimise', 'motion analysis', 'skin movement', 'soft tissue displacement', 'artifact' and 'error'. Key search terms were matched with medical subject headings (MeSH) and exploded to include all subheadings where relevant. Truncations and wildcards were used to enable the search to retrieve all possible variations of a specific root word. Targeted searching was conducted to identify literature that may have been overlooked by electronic database searching. This included online searching of journals likely to contain relevant articles. A manual search of reference lists of relevant studies also identified articles for the review.

2.2. Inclusion and exclusion criteria

The titles and abstracts of articles retrieved from the search strategy were assessed by a single reviewer (AP). Articles were included when they satisfied the following criteria: (1) study included human participants, (2) gait or functional tasks were investigated, (3) an implied or documented objective to quantify STA in the article, (4) 2D or 3D motion analysis techniques, (5) pelvic and or lower limb data, and (6) full scientific papers and abstracts. Excluded from the review were studies published only as conference proceedings and articles using artificial or additive error [9].

2.3. Data extraction

A customised data extraction form was developed based on previous systematic reviews of associated areas [10–13]. The major data extraction themes were; introduction, equipment and setup, methodology, results, discussion and conclusion. These themes were selected to create a comprehensive illustration of each article for analysis and assessment of the quality of the available scientific literature. Three reviewers (AP, BG and MS) piloted the data extraction form to ensure review process was reliable.

Table 7
Recommendations for future STA studies.

Domain	Recommendation
Methods	
Participants	Inclusion criteria. Recruitment strategy.
Equipment and setup	Description of laboratory setting, data capture setting, marker set description (in sufficient detail to be reproduced), biomechanical model (in sufficient detail to be reproduced).
Study design	Tested movement task.
Sample size	How has sample size been determined?
Statistical methods	Description of statistical methods. Do these provide outcomes with the same units as the measured variables to ensure generalisability of results?
Results	
Participants	Adequate description of participant characteristics.
Data	Report of descriptive measures as well as more complex movement data. Always examine entire range of movement to ensure completeness of results.
Implications	Consider impact on clinical practice.
Discussion	
Limitations	Critical discussion of limitations of results.
Outcomes	Comparison of results with those already published in the literature.

results for the tibia. This study used cadaver specimens. In doing so, much of the contribution of muscular contractions would be removed from the measurement of STA. On the other hand, Sangeux et al. [39] reported pessimistic findings for the knee. This could be attributed to the technique used for obtaining results. Indirect measurements from the Finite Helical Axis (FHA) description of the analysed movement were used which is known to be sensitive to measurement inaccuracies.

The activity performed was considered to affect the amount of STA in kinematic measurements in a number of studies [5,8,33]. Fuller et al. [8] investigated cycling and walking activities, the results show little difference in the effect of STA at both the greater trochanter and the lateral epicondyles. Stagni et al. [33] investigated hip extension and sit-to-stand (STS) activities and the STA effect on the thigh and shank marker clusters. Interestingly, the effect was reversed between the thigh and shank, where STS produced greater error at the thigh, and hip extension produced greater error at the shank. Cappozzo et al. [5] also investigated STA at various anatomical landmarks during different joint movements. They found maximal errors at the greater trochanter during hip extension, lateral epicondyles and head of the fibula during knee flexion and lateral malleolus during ankle flexion. These findings show that maximal errors will be encountered when a segment undergoes movement, or when a marker location is on a joint line [29].

There were no differences between direct and indirect measurements of STA. Both found the thigh to have the greatest error due to STA followed by the foot and ankle. Both measurements also showed tibial segment kinematics to be less affected by STA than the thigh and foot.

4.4. Limitations

There were several limitations of this systematic review. The search strategy was specifically designed to include only English language publications; therefore some articles may have been overlooked. Considerable emphasis was put on subjective opinions of reviewers. The quality scoring system was particularly generous in some domains with a score of “1” requiring only partial explanations, for example, basic descriptive statistics were awarded a score of “1” in the statistical analysis domain. This could affect the quality outcome of the reviewed article, implying a better result than may be realistic.

5. Conclusions

Despite the quality of the literature being generally high, there were no conclusive solutions to the issue of STA in human motion analysis. Reviewed studies have shown the effect of STA is dependant upon marker location, activity performed, the instrumented segment and individual participant characteristics. STA was found to be in the vicinity of 40 mm for some areas of the thigh. The results indicated that the tibia is less susceptible to STA, shown by the decrease in direct and indirect error measurements reaching maxima of no greater than 12 mm. Whilst it is possible to draw such broad conclusions from these studies, it is important to bear in mind that methodological limitations of experimental work limit the confidence that can be placed upon many of the more detailed measures. Future work to more accurately measure STA [43–45] validated by medical imaging modalities may still be required in order to progress our understanding of STA and devise effective methods compensating for it in 3D human motion analysis.

Conflict of interest

A/Prof Richard Baker and Dr Morgan Sangeux receive research funding from Vicon (Oxford, UK).

Acknowledgements

This work is supported by the Murdoch Children’s Research Institute at the Royal Children’s Hospital, Melbourne, and The School of Physiotherapy at The University of Melbourne in Victoria, Australia. Alana Peters and Brook Galna received funding provided by the National Health and Medical Research Council of Australia.

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Please cite this article in press as: Peters A, et al. Quantification of soft tissue artifact in lower limb human motion analysis: A systematic review. Gait Posture (2009), doi:10.1016/j.gaitpost.2009.09.004