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Correcting lower limb segment axis misalignment in gait analysis: A simple geometrical method

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ABSTRACT

Background: Obtaining precise and repeatable measurements is essential to clinical gait analysis. However, defining the thigh medial-lateral axis segment remains a challenge, with particular implications for the hip rotation profile. Thigh medial-lateral axis misalignment modifies the hip rotation profile and can result in a phenomenon called crosstalk, which increases knee adduction-abduction amplitude artificially.
Research question: This study proposes an a posteriori geometrical method based solely on segment anatomy that aims to correct the thigh medial-lateral axis definition and crosstalk-related error.
Methods: The proposed method considers the thigh medial-lateral axis as the normal to the mean sagittal plane of the lower limb defined by hip, knee and ankle joint centres during one gait cycle. Its performance was compared to that of an optimisation method which repositions the axis to reduce knee abduction-adduction variance. An existing dataset was used: 75 patients with a knee prosthesis undergoing gait analysis three months and one-year post-surgery.

Three-dimensional hip and knee angles were computed for two gait analysis sessions. Crosstalk was quantified using both the coefficient of determination (r^2) between knee flexion-extension and adduction-abduction and the amplitude of knee adduction-abduction. The reproducibility of hip internal-external rotation was also quantified using the inter-trial, inter-session and inter-subject standard deviations and the intraclass coefficient (ICC).
Results: Crosstalk was significantly reduced from $r^2 = 0.67$ to $r^2 = 0.51$ by the geometrical method but remained significantly higher than with the optimisation method with a $r^2 < 0.01$.
Significances: Both methods allowed to improve the hip internal-external reproducibility from poor to moderate (original data: ICC = 0.34, geometrical method: ICC = 0.65, optimisation method ICC = 0.73). One advantage of the geometrical method is that, unlike the optimisation method, it does not require much movement, making it suitable for a wider range of patients.

1. Introduction

Clinical gait analysis helps clinicians identify gait impairments, thus guiding therapeutic choice (e.g. surgical planning, rehabilitation) in various pathologies (e.g. cerebral palsy, stroke) [1]. However, the joint kinematics involved are often computed with the Conventional Gait Model (CGM) [2] developed in the 80's, which has several shortcomings. The most common is marker mislocations, which can lead to segment axis misalignment; this can impact the accuracy of the hip rotation profile [3]. Hip rotation is a critical outcome, but one prone to error [4]. The medial-lateral axis direction is dependent on the positioning of a wand (or a medial marker) on the thigh. The wand should be positioned in the thigh's frontal plane. This plane can, however, be difficult to define in patients with skeletal deformities: for example, patients with cerebral palsy can exhibit major femoral growth abnormalities such as femoral torsion [5]. The resulting misalignment of this medial-lateral axis, which is used to define the flexion-extension axis of the distal joint, leads to a phenomenon called crosstalk. Crosstalk at the knee implies unrealistic adduction-abduction amplitude [3]. Furthermore, a misalignment of the medial-lateral axis can also lead to errors on the internal-external rotation of the hip joint [6].

Several experimental and computational solutions have been proposed to reduce these errors. One solution is to change the protocol (number and placement of markers) [7]. Devices such as the Knee

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