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# Gait patterns in association with underlying impairments in polio survivors with calf muscle weakness

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ABSTRACT

The objective was to identify gait patterns in polio survivors with calf muscle weakness and associate them to underlying lower extremity impairments, which are expected to help in the search for an optimal orthosis.

Unilaterally affected patients underwent barefoot 3D-gait analyses. Gait pattern clusters were created based on the ankle and knee angle and ankle moment shown in midstance of the affected limb. Impairment clusters were created based on plantarflexor and knee-extensor strength, and ankle and knee joint range-of-motion. The association between gait patterns and underlying impairments were examined descriptively. The Random Forest Algorithm and regression analyses were used to predict gait patterns and parameters.

Seven gait patterns in 73 polio survivors were identified, with two dominant patterns: one with a mildly/non-deviant ankle angle, ankle moment and knee angle (n = 23), and one with a strongly deviant ankle angle and a mildly/non-deviant ankle moment and knee angle (n = 18). Gait pattern prediction from underlying impairments was 49% accurate with best prediction performance for the second dominant gait pattern (sensitivity 78% and positive predictive value 74%). The underlying impairments explained between 20 and 32% of the variance in individual gait parameters.

Polio survivors with calf muscle weakness who present a similar impairment profile do not necessarily walk the same. From physical examination alone, the gait pattern nor the individual gait parameters could be accurately predicted. The patient's gait should therefore be measured to help in the prescription and evaluation of orthoses for these patients.

## 1. Introduction

Poliomyelitis is a highly infectious viral disease that has left many polio survivors with permanent muscle weakness [1], often including the calf muscles. Gait in calf muscle weakness is typically characterized by instability of the ankle and knee [2,3] and by an increased walking effort [2,4,5], which may hamper daily-life activities [6].

To compensate for loss of calf muscle function and improve gait, a dorsiflexion restricting ankle-foot orthosis (DR-AFO) can be provided. Dorsiflexion restriction aims to allow an external dorsiflexion moment around the ankle without causing instability [7–9], and it may reduce walking effort [10]. Previous research in polio survivors with calf muscle weakness, however, suggests that the efficacy of DR-AFOs to improve stability and reduce walking effort is partly dependent on the patients' gait deviations when walking without an orthosis [10]. Hence, when prescribing a DR-AFO for calf muscle weakness, a clear understanding of the gait pattern deviations is important.

Gait pattern deviations due to calf muscle weakness have been previously investigated [7,11–14]. Yet, available studies lack a complete description of the joint kinetics of gait in addition to joint kinematics, while both contain important information of the resultant gait deviations and compensatory strategies. Furthermore, in most studies [11–13] gait was assessed in healthy subjects with a temporarily induced isolated calf muscle paralysis, while in polio survivors calf muscle weakness is rarely isolated, often not fully paralytic, and almost always accompanied with other lower extremity impairments such as muscle and joint contractures and bony deformities. Available gait descriptions in polio survivors have not yet been related to underlying impairments of the lower extremities, although the gait pattern may depend on these [4,10]. Better insight in the gait pattern characteristics associated with calf muscle weakness is expected to help in the search for an optimal effective DR-AFO [7,15].

The aims of this study in polio survivors with calf muscle weakness were to identify discrete gait patterns; relate the identified gait patterns to underlying impairments of the lower extremities; and determine whether, based on these underlying impairments, the gait pattern and

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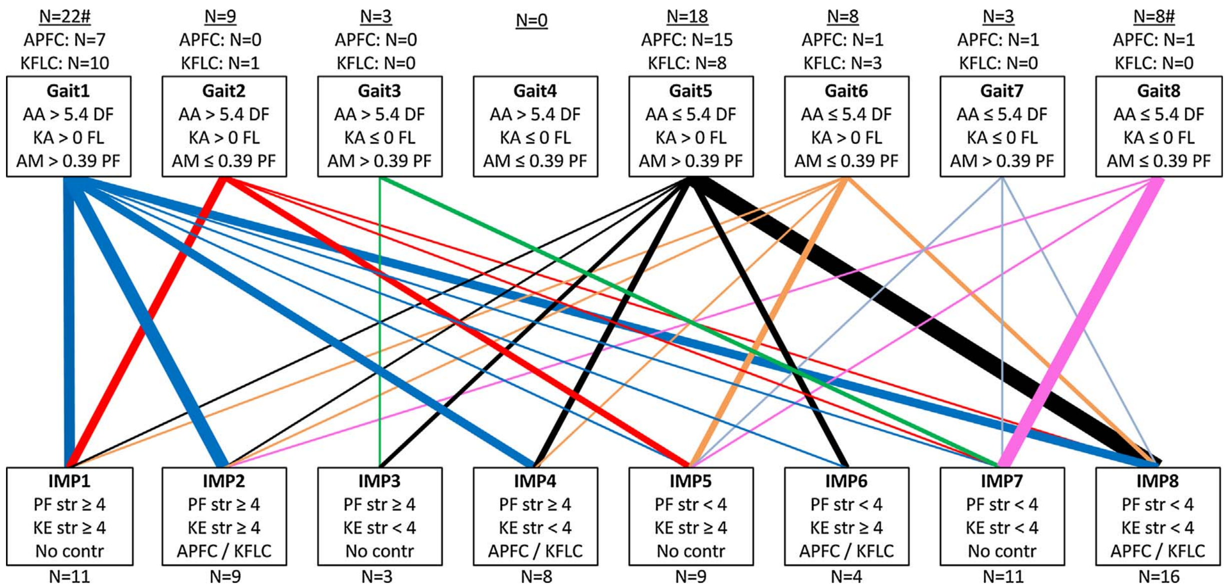


**Fig. 1.** Relationship between gait patterns (Gait) and impairment clusters (IMP); thicker interconnection lines represent a higher number of limbs. All values in the figure are cut-off values, splitting the parameters into 'mildly/ non-deviant or mildly/ non-affected' (denoted by > or ≥) and 'strongly deviant or strongly affected' (denoted by < or ≤) from normal. Angles and moments are expressed as a maximum value in midstance.

N: number of limbs, #: 1 limb missing due to missing physical examination parameters, AA: ankle joint angle (degrees), KA: knee joint angle (degrees), AM: ankle joint moment internal (Nm/kg), DF: dorsiflexion, PF: plantarflexion, FL: flexion, KE: knee extension, APFC: ankle plantarflexion contracture, KFLC: knee flexion contracture, No contr: no contracture of the ankle and knee joint, str: strength (expressed as a medical research council (MRC) score).

Example descriptors of gait and impairment:

Gait pattern 5 is of patients of which, in the affected limb in midstance, the maximum ankle angle is smaller than or equal to 5.4 degrees dorsiflexion (which is at least two standard deviations below normal dorsiflexion), the maximum knee angle is in flexion, and the maximum internal ankle moment is larger than 0.39 Nm/kg plantarflexion (which is within two standard deviations of normal).

Impairment cluster 2 is of patients of which, in the affected limb in midstance, ankle plantarflexion strength and knee extension strength are equal to or larger than MRC 4 and who have an ankle plantarflexion contracture and/or a knee flexion contracture.

single gait parameters could be predicted.

## 2. Methods

### 2.1. Study population

A retrospective search of the gait laboratory database at our university hospital outpatient Rehabilitation and Polio Expertise Center was conducted for selecting polio patients who had undergone barefoot three-dimensional (3D) gait analyses within a patient-care setting. Inclusion criteria for selecting patients were presence of muscle weakness in a single limb, presence of calf muscle weakness in that limb (defined as a score < 5 according to the Medical Research Council (MRC) scale, and/or being unable to perform > 3 heel rises, and/or fatty infiltration in comparison with the contralateral side seen on MRI or CT scan images of the calf muscles), and the availability of valid 3D gait data and physical examination data of the lower extremities. An exclusion criterion was the use of assistive devices during the 3D gait analysis.

The database search revealed 87 polio patients with unilateral calf muscle weakness who had undergone a barefoot 3D gait analysis without using assistive devices. From these 87 patients, 14 patients were excluded due to invalid 3D gait data. This left 73 patients (mean ± SD age 55 ± 13 years, polio at median [interquartile range] age 2 [1–3] years, 35 female), for which we identified a gait pattern.

### 2.2. Physical examination

Clinical data of patients were extracted from patient records. Muscle strength of the hip flexors, extensors, abductors and adductors, knee extensors and flexors, and ankle dorsal- and plantarflexors was manually tested by trained and experienced examiners, and scored according to the MRC scale (range 0–5) [16]. Passive range-of-motion in the hip, knee, and ankle joints in the sagittal plane was determined using a single-axis goniometer [17]. Inter-rater reliability of manual muscle strength testing is found to be excellent [18], and of passive joint range of motion assessment in the sagittal plane acceptable [19].

### 2.3. Gait analysis

3D gait analysis was performed with an eight-camera VICON MX1.3 motion capture system operating at a sample rate of 100 Hz using the Plug-in Gait model (VICON, Oxford, UK). The ground reaction forces on the left and right foot were recorded using two force plates in series that were set flush with the floor and sampled data at 1000 Hz (OR6-7, AMTI, Watertown, MA, USA). Simultaneously, patients were captured on four digital videos in the sagittal and frontal plane (720C Bonita (VICON) or 602 fc (Basler AG, Ahrensburg, Germany) at 100 Hz).

Gait data were checked for errors caused by technical failure and marker misplacement. Video analysis with force vector overlay was used to validate the 3D data if i) 3D data showed knee hyperextension angles while physical examination revealed a knee flexion contracture or ii) the internal knee moment in midstance was extending while physical examination revealed severe quadriceps weakness (MRC < 4). When the 3D gait data did not correspond with the video data, it was considered non-valid and the patient was excluded. When 3D gait data did correspond with the video data, physical examination scores were re-assessed and, if possible, adjusted; otherwise the patient was excluded.

For each patient, three valid 3D gait trials were selected in which markers were visible from first heel strike on the force plate to subsequent ipsilateral heel strike, and that contained clean foot strikes on the force plate. Valid trials were processed with standard Plug-In-Gait pipelines (VICON Nexus 1.8.5, Oxford, UK) and time-normalized with spline interpolation and then averaged, using a custom written Matlab script (version R2014a, The MathWorks, Inc., Natick, MA, U.S.A.).