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Which functional impairments are the main contributors to pelvic anterior tilt during gait in individuals with cerebral palsy?

Sebastian I. Wolf [a,*], Ralf Mikut [b], Andreas Kranzl [c], Thomas Dreher [a]

[a] *Heidelberg University Clinics, Department for Orthopedic and Trauma Surgery, Schlierbacher Landstraße 200a, 66118 Heidelberg, Germany*
[b] *Department for Applied Computer Science, Karlsruhe Institute of Technology (KIT), Hermann-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen, Germany*
[c] *Department for Pediatric Orthopaedics, Orthopaedic Hospital Speising, Speisingerstrasse 109, Vienna, Austria*

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ABSTRACT

While past investigations focused on describing pelvic motion patterns in the frontal and transversal plane, the sagittal plane "double bump" pattern commonly found in children with cerebral palsy was only rarely investigated, especially concerning the underlying pathology.

375 ambulatory (GMFCS I–III) patients with bilateral spastic cerebral palsy were included in this study. Gait and clinical data (ROM, strength, spasticity) were classified in two different ways: (a) into two groups of normal and enhanced mean anterior pelvic tilt and (b) into two groups of moderate and excessive ROM in pelvic tilt.

The results reveal that increased mean pelvic tilt is mainly associated with gait features of reduced hip extension and increased pelvic and trunk obliquity ROM but with increased knee ROM. In the clinical exam this corresponds to a smaller passive knee extension deficit and reduced knee flexor strength. It seems that flexors to extensors strength imbalance at the knee is a major feature why mean pelvic position is tilted anterior whereas maximum passive hip extension is of minor importance.

Contrarily, excessive sagittal pelvic ROM is associated with increased knee flexion at initial contact and reduced knee ROM. Furthermore, Duncan-Ely- and Tardieu-tests show both increased values in this group with excessive pelvic range of motion indicating for spastic rectus femoris activation.

The results of our study indicate that the two gait variables are influenced by different specific mechanisms which are now described for the first time. Since the pelvis plays a central role during gait, these findings should be considered when planning single event multilevel surgery in patients with cerebral palsy.

1. Introduction

Increased pelvic anterior tilt in children with cerebral palsy is a common finding and has frequently been described [1,2]. It is a typical gait deviation in the natural functional progression in these children [3] and it also may present as a common sequelae after inadequate muscle lengthening, especially hamstring lengthening [1,4]. By automated methods it has been found that increased range of pelvic motion in the sagittal plane often visible in a typical "double bump pattern" is even more characteristic for cerebral palsy (CP) gait then the average anterior tilt within the gait cycle [5]. However, no attempt has yet been made to specifically elucidate the factors of each phenomenon. Hence, the underlying mechanisms are not fully understood.

Motion of the pelvis is complex as it mediates the inter-limb coordination and the coordination between trunk and lower extremity. In the transverse plane, pelvic positioning and motion, i.e. pelvic retraction, is a means to compensate rotational bony mal-alignments in the lower extremity [6]. Due to symmetry arguments this is more relevant in patients with unilateral involvement than in those with bilateral involvement [6,7]. Further, excessive ankle plantar flexion can be a factor leading to pelvic retraction [8].

Several factors have been postulated leading to increased anterior pelvic tilt: hamstring weakness [9] or inadequate hamstring lengthening [1,10], rectus spasticity and psoas contracture, spasticity [11,12] or trunk muscle weakness [13].

However, these mechanisms were never further investigated and connected to the pelvic pattern in the sagittal plane. For classification and assessments of gait patterns in CP most frequently features in the distal joints, i.e. knee and ankle kinematics, have been chosen [14] whereas motion of the hip

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[*] Corresponding author. Tel.: +49 6221 562 6724.
E-mail address: sebastian.wolf@med.uni-heidelberg.de (S.I. Wolf).

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and the pelvis has little been monitored – and this with a focus on the transverse plane only [6,7]. Any quantitative reports on trunk–pelvis coordination are missing most probably because trunk models are still little in use for conventional 3D-gait analysis. However, since pelvic position and motion is of major importance for gait and postural stability, there is a need for further investigation. Clinical relevance is given since procedures such as hamstring lengthening in the context of single event multilevel surgery (SEMLS) are frequently found to negatively influence pelvic tilt [1,4,10]. The purpose of this study therefore was to identify the primary factors (muscle contractures, weakness or spasticity) influencing specifically the ROM in pelvic tilt and to set them in context to those leading to increased mean pelvic anterior tilt. In other words, the goal was to check in how far ROM and mean pelvic tilt are independent functional symptoms associated with different clinical findings.

2. Methods

This study included 375 ambulatory patients (GMFCS I–III) with bilateral spastic cerebral palsy (BSCP) selected from the database of the Heidelberg motion lab. Inclusion criteria were a documentation of a standardized clinical examination including passive ranges of motion of the joints of the lower limbs, the lower limbs muscle strength according to the rectus spasticity and an instrumented 3D gait analysis (3D-GA). Muscle strength was assessed according the Medical Research Council (MRC) [15] with the following grading: 0 = “No muscle contraction”; 1 = “flicker or trace of contraction”; 2 = “active movement with gravity eliminated”; 3 = “active movement against gravity”; 4 = “active movement against gravity and resistance”; 5 = “normal power”. The spasticity of the rectus was tested both by the Duncan-Ely test [16] and by the Tardieu test [17]. The Duncan-Ely test is considered positive (1) if during the passive knee flexion the patient in prone position simultaneously flexes the ipsilateral hip or resistance is felt by the examiner. The spasticity grade of the Tardieu scale further in detail grades this resistance under fastest passive knee flexion velocity possible for the examiner from no spasticity (0) to severe spasticity (4).

Only first visits were included. For reference, an age-matched group of 50 normally developing subjects was selected who underwent the same examination protocol.

For standardized 3D-GA, optical marker based motion capture was performed according to Kadaba et al. [18] to obtain kinematics of pelvis and hip, knee and ankle joints. Additional markers on trunk (C7) and shoulders (Acromiai: LSHO, RSHO) allowed calculation of trunk kinematics by defining the trunk segment via a trunk axis through the two reference points

$$\mathrm{ThoraxC} = (\mathrm{LSHO} + \mathrm{RSHO}) \times 0.25 + \mathrm{C7} \times 0.5$$

and

$$\mathrm{PelvisC} = (\mathrm{LASI} + \mathrm{RASI} + \mathrm{SACR}) \times \frac{1}{3}$$

and the medio-lateral axis through both shoulder markers.

Kinetics was determined via two Kistler force plates and calculated with conventional software by Vicon (Vicon Clinical Manager and Plug-in-Gait). Data of kinematics and kinetics data were collected for a minimum of five strides and averaged accordingly after time normalization. For dynamic EMG, data from the muscles biceps femoris, gastroc, lateralis, gluteus medius, rectus femoris, semimembranosus, soleus, tibialis anterior, and vastus lateralis were collected according to the SENIAM guidelines [19]. Linear envelopes of EMG-data were normalized to the mean value for each muscle of each step and subject respectively.

3. Data analysis

For analysis, the following 30 gait parameters were calculated:

- Gillette gait index including 16 variables of gait kinematics.
- Mean angles and ROMs of pelvis and trunk.
- ROMs of hip, knee and ankle.
- Range of muscle activity (maximum-minimum of normalized linear envelope of EMG) during gait (eight muscles).

From the clinical exam the following data were extracted:

- Contractures (five parameters): Maximum hip and knee extension and maximum dorsiflexion (in knee extension), midpoint between maximum internal and external hip rotation as well as popliteal angle.
- Strength (seven parameters): hip flexors, extensors, and abductors; knee flexors, extensors and dorsi- and plantar flexors (MRC).
- Spasticity (two parameters): Tardieu and Duncan.

Further, the GMFCS was included in the analysis.

Fuzzy c-means-cluster method (with fuzzifier $C = 2$) [20] was applied with respect to the parameters mean pelvic tilt and ROM of pelvic tilt in order to obtain classifiers to separate between two patient groups for each parameter, respectively. For testing normality of features of the complete group of subjects with CP and of the clusters, a Jarque–Bera-test was applied showing that many features violate the normality hypothesis. Consequently, we applied non-parameteric Mann-Whitney-*U*-tests and Spearman correlations. Results were classified according to strength of association, i.e. values of 0.00–0.25 represent little or no association; 0.25–0.50 represents fair association; 0.50–0.75 moderate to good and 0.75–1.00 represents good to excellent association [21]. For the 54 features tested, Bonferroni corrections were applied according to parameter group sizes (i.e. 30 gait data, five contracture related data, seven data on strength and two for proximal spasticity).

4. Results

4.1. Classification

For illustration of the distribution of the two key parameters mean pelvic tilt and ROM pelvic tilt in the group of subjects with CP an *x*–*y*-plot is given in Fig. 1. With the Fuzzy c-means-cluster method 200 subjects were classified having “moderate ROM” below 8° (average: 5.4°; diamonds in Fig. 1; average normal reference: 2.8°; black triangles) and 175 subjects were classified having “excessive ROM” in pelvic tilt above 8° (average: 11.1°, circles in Fig. 1), respectively. Similarly in mean pelvic tilt, 165

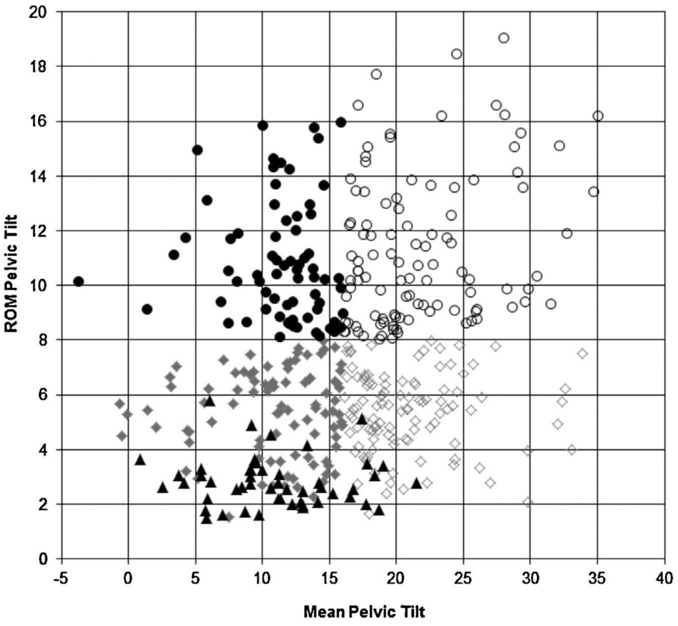

Fig. 1. Fuzzy c-means clusters in the group of involved subjects with CP according to mean pelvic tilt (solid and hollow symbols) and pelvic ROM (circles and diamonds). Black triangles indicate data of non-involved reference subjects.