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Three-dimensional evaluation of skeletal deformities of the pelvis and lower limbs in ambulant children with cerebral palsy

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ABSTRACT

Skeletal abnormalities, affecting posture and walking pattern, increase with motor impairment in children with cerebral palsy (CP). However, it is not known whether these skeletal malalignments occur in children with slight motor impairment. Our aim was to evaluate skeletal malalignment at the level of the pelvis and lower limbs in ambulant children with CP, with slight motor impairment, using a low dose biplanar X-ray technique.

Twenty-seven children with spastic CP (mean age: 10.9 ± 4 years, 7 Hemiplegia, 20 Diplegia, GMFCS levels I:17, II:10), with no previous treatments at the hips and knees, underwent EOS® biplanar X-rays. A control group consisting of 22 typically developing children was also included. Three-dimensional reconstructions of the pelvis and lower limbs were performed in order to calculate 11 radiological parameters related to the pelvis, acetabulum and lower limbs.

Pelvic incidence and sacral slope were significantly increased in children with CP compared to TD children (48° ± 7° vs. 43° ± 8°, 42° ± 7° vs. 38° ± 5°, respectively, $p = 0.003$). Acetabular parameters did not significantly differ between the two groups. Femoral anteversion and neck shaft angle were significantly increased in children with CP (25° ± 12° vs. 14° ± 7°, $p < 0.001$; 134° ± 5° vs. 131° ± 5°, $p = 0.005$ respectively). No difference was found for tibial torsion.

This study showed that even slightly impaired children with CP have an anteverted and abducted femur and present positional and morphological changes of the pelvis in the sagittal plane. The orientation of the acetabulum in 3D seems to not be affected when children with CP present slight motor impairment.

1. Introduction

Cerebral Palsy (CP) is a neurological disorder that can cause muscle spasticity. The increased muscle tone of patients with CP is known to affect their posture and walking pattern [1]. Skeletal malalignments of the lower limbs are often encountered in children with CP in the three planes [2–4] and are mainly caused by spasticity, abnormal posture, delays in gaining independent walking as well as gait alterations [5].

Previous studies have reported that skeletal malalignments of the lower limbs increase with motor impairment [2,6]. These studies have described only a few femoral parameters (neck shaft angle and femoral parameters) in different groups of CP that differed by their motor impairment but did not compare their results to those of control groups [2,7]. Moreover, it is not known whether these skeletal malalignments occur even in children with slight motor impairment.

Other studies have reported skeletal abnormalities of the hip and acetabulum in children with CP, such as hip dysplasia or acetabular deficiencies [8,9]. It was suggested that these abnormalities, which had been reported in severely affected children

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with CP, were mainly due to abnormal weight-bearing on the lower limbs. Since slightly impaired children with CP also present abnormal weight-bearing, it would be interesting to elucidate whether their acetabular parameters are affected as well.

The assessment of skeletal malalignments is important in surgical decision-making for children with CP [10], and is usually based on physical examination [11], two-dimensional X-Ray imaging [12] and three-dimensional (3D) gait analysis [13]. However, torsional abnormalities, such as abnormal femoral anteversion (FA) or tibial torsion (TT), require measurements in 3D.

Three-dimensional computed tomography (CT) is a reliable tool to measure FA and TT [10]. This technique has been used to measure these parameters in children with CP [6]. However, the use of this technique is limited by the high exposure to radiation [14] and the fact that its accuracy is affected by positional variables [10], which are difficult to control in children with CP. For these reasons, 3D CT scan is not routinely used to assess lower limb skeletal abnormalities in children with CP.

Low dose biplanar X-rays have been previously found to be a fast and reliable tool for the measurement of skeletal malalignments in the standing position [15–17]. This technique allows quantification of subject-specific skeletal parameters based on 3D reconstruction of the pelvis and lower limbs [16,18] and could be a viable alternative to CT in daily practice.

The aim of this study was to investigate whether ambulant children with CP, with slight motor impairment, present skeletal deformities at the pelvis and lower limbs, using the low dose biplanar X-ray technique.

2. Methods

2.1. Population

This is an IRB approved cross-sectional case-control review of a consecutive series of children with CP who underwent full body low dose biplanar radiographs using EOS® system (EOS Imaging, Paris France), in the setting of their pre-treatment evaluation.

Twenty-seven children with spastic CP (17 boys, 10 girls) were included. Motor impairment was defined according to GMFCS E&R levels [19]. Children with a history of previous orthopedic interventions (botulinum toxin, casting, surgery), other than those directed to treat equinus (botulinum toxin in gastrocnemius, lengthening) at least one year prior to the enrollment in the study, were excluded.

Twenty-two typically developing (TD) children (11 boys, 11 girls), for whom biplanar radiographs of their lower extremities had been prescribed for atypical pain and had not shown any abnormality, were included in the study (Table 1). The parents of the children in the CP and TD groups were informed of the possible use of their child's radiographs for research purposes and they approved and signed a written consent form.

2.2. Acquisition and 3D reconstruction

EOS® biplanar X-ray acquisition was performed in the standing position. The lower limbs were slightly shifted in the sagittal plane, in order to avoid knee overlap on the lateral view therefore facilitating 3D reconstruction [15]. Typically developing children and children with CP were asked to stand in the free standing position, with hands on cheeks and flexed elbows [20]. This position is known to reproduce the natural posture of the subject. Children with CP were allowed, when necessary, to put their hands on the embedded bar in the EOS® cabin for better stability, without it affecting their natural posture.

One trained operator performed all 3D reconstructions of both lower limbs using SterEOS® (version 1.6.4.7977) based on a previously described method [15]: a few geometrical primitives and axes are first digitalized, in order to obtain a simplified personalized parametrical model. Then, a 3D morpho-realistic parametric model, based on a database of CT-Scan reconstructions, is deformed. This deformation is based on statistical shape modeling. Pelvic reconstruction is based on the same technique used for the lower limbs and is performed using a dedicated software developed at Arts et Métiers ParisTech [21] (Fig. 1).

2.3. Radiological parameters

Pelvic, acetabular, femoral and tibial parameters were automatically calculated from the 3D reconstructions of the pelvis and lower limbs of each subject. Eleven radiological parameters were chosen according to their clinical relevance in the diagnosis and decision-making for children with CP. Some of these parameters are routinely used: pelvic incidence (PI), sacral slope (SS), pelvic tilt (PT), femoral anteversion (FA), neck shaft angle (NSA) and tibial torsion (TT). Acetabular parameters are less used in the management of CP: 1) acetabular anteversion (AAnt) reflects the rotation of the acetabulum around the vertical axis [22]. In order to render this angle morphological, the vertical axis was defined as the perpendicular to the sacral plate; 2) acetabular inclination (AInc) reflects the rotation of the acetabulum around the postero-anterior axis, defined as a parallel to the sacral plate [22,23]; 3) acetabular tilt reflects the rotation of the acetabulum around the medio-lateral axis of the pelvis [24]. The list and the description of each of these parameters are detailed in Table 2 and displayed in Fig. 2. These parameters were calculated for both limbs of the children in the CP and TD groups. The unaffected limbs of children with hemiplegia were excluded from further analysis. The mean values of the pelvic, acetabular and lower limb parameters were also separately calculated for children with GMFCS levels I (N = 17) and II (N = 10).

2.4. Statistics

Comparisons between demographic and radiological parameters of CP and TD children were performed using Student's *t*-test, Mann–Whitney's test or Welch's unequal variances *t*-test. Significance level was set at 0.05.

Means comparison between TD children and CP sub-groups (GMFCS levels I and II) were performed using one-way analysis of variance (ANOVA) with Hochberg's GT2 post-hoc test. Variances of parameters between CP and TD groups were compared using Levene's test.

Table 1
Demographic characteristics of the typically developing children (TD) and children with cerebral palsy (CP). Distribution of the children with CP according to the Gross Motor Classification System (GMFCS).

Groups	Age (years)	Weight (kg)	Height (cm)	N	Spastic Hemiplegia/Diplegia (N)	GMFCS Levels: I/II (N)
	Mean ± SD (min–max)	Mean ± SD	Mean ± SD			
TD children	12 ± 3 (6.5–19)	44.4 ± 13.8	149.9 ± 15	22		
CP children	10.9 ± 4 (6–19.6)	42.2 ± 20	140.1 ± 20	27	7/20	17/10