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Association of back pain and pelvic tilt during gait in individuals with cerebral palsy

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ABSTRACT

Background: Back pain prevalence may increase with lumbar lordosis during standing in individuals with cerebral palsy (CP). Multiple interventions undertaken in individuals with CP have been shown to increase anterior pelvic tilt.

Research question: Are pelvic tilt and trunk tilt (proxy measurements for lumbar lordosis) during gait associated with back pain prevalence in ambulatory individuals with CP?

Methods: A retrospective investigation was performed among all patients with cerebral palsy visiting a single clinical motion analysis laboratory over a 3.5 year period (January 2015 – May 2018) who also had complete pain questionnaire data. Back pain prevalence and its association with sagittal plane kinematic parameters (pelvic tilt and trunk tilt) were analyzed.

Results: Among the 700 patients that met the inclusion criteria, 594 were children and 106 were adults. Back pain prevalence was 11.1% in children and 36.8% in adults. As pelvic tilt and age increased, back pain increased (odds ratio 95% confidence interval: 1.002–1.061 and 1.052–1.109, respectively). Walking with an assistive device was not associated with back pain, nor was trunk tilt.

Significance: Back pain was more common with increasing age in ambulatory individuals with CP. After controlling for assistive device use and age, there was a weak relationship between pelvic tilt and back pain. Future studies are needed to determine if this is this a causal relationship.

1. Background

Cerebral Palsy (CP) is a life-long disorder of the central nervous system secondary to a non-progressive insult to the developing brain, resulting in permanent disorders of movement accompanied by secondary musculoskeletal deformity [1–3]. Chronic pain is more prevalent in the CP population compared to the general population [1,4–6], and this pain is associated with fatigue, low life satisfaction, and deteriorating physical function [4].

Back pain is the most commonly reported type of chronic pain in adults with CP [1,4,7] and is among the most common for adolescents with CP [8–10]. Lumbar hyperlordosis may contribute to low back pain (LBP). In a neurologically typical population, some researchers have found more anterior pelvic tilt/lumbar lordosis in those with or who develop LBP [11–17], others have found no relationship [13,18–20], while still others have found a less anterior pelvic tilt/lumbar lordosis in those with LBP [20]. Multiple authors have shown that children with CP have, on average, increased anterior pelvic tilt while walking [21–23]. Harada and colleagues [24] reported that radiographic lumbar lordosis was greater in 84 patients with CP compared to 50 typically developing individuals, and that back pain prevalence in the CP population was higher for those with hyperlordosis.

Certain surgical procedures may contribute to increased pelvic tilt postoperatively. In the treatment of flexed-knee gait using distal femur extension osteotomy (DFEO), patellar tendon shortening (PTS), hamstring lengthening (HSL), and the combination of DFEO and PTS, anterior pelvic tilt may increase an average of 1.3–14° [25–35]. Selective dorsal rhizotomies may also cause increased anterior pelvic tilt both in the short-term and long-term [36–38]. Other postoperative outcome studies have not reported these findings [39,40].

Ashmen et al. [41] asserted that excessive anterior pelvic tilt will result in abnormal lumbar spine compressive forces. Anatomically, lumbar hyperlordosis is considered a generator of compressive forces on the posterior vertebral elements such as pars interarticularis, leading to stress fractures (spondylolysis) or complete disruption and anterior shift of the cephalad vertebral body (spondylolisthesis) [17]. If

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increased anterior pelvic tilt and posterior trunk tilt, indirect measures of lumbar lordosis available by instrumented motion analysis, cause LBP in patients with CP, the iatrogenic consequences of certain surgical procedures can be considered by families and surgeons undertaking limb surgery. Our purpose was to conduct a large scale retrospective study to determine if anterior pelvic tilt during gait is associated with back pain in individuals with CP. We hypothesized that back pain prevalence would significantly increase with more anterior pelvic tilt. A secondary analysis was performed to see if trunk tilt during gait, another pseudo-measure of lordosis, was related to back pain. We hypothesized that back pain prevalence would significantly increase with less trunk tilt (i.e., more lumbar lordosis).

2. Methods

This was an IRB-approved retrospective review of all patients with a diagnosis of CP undergoing full instrumented motion analysis at a single clinical motion analysis laboratory (Gillette Children's Specialty Healthcare) between January 2015 and May 2018. Patients of all ages were included, though the laboratory predominantly serves a pediatric population.

Back pain was consistently documented on the Gillette Functional Assessment Questionnaire by parent/guardian/self as part of standard of care (Fig. 1). Because back pain prevalence increases with age [42], the most recent visit was chosen for analysis if a patient had multiple visits during the study period. Only patients with completed questionnaire data were included.

The Back Pain group in this study included patients who indicated they were currently experiencing pain in the lower back, upper and lower back, or indicated when back pain occurred without specifying the location. The No Back Pain group included patients who did not indicate any back pain (lower, upper, both). A modified Helen-Hayes marker set was used for kinematic data collection [43]. The pelvis was defined by four markers (two each on the anterior and posterior superior iliac spines– ASIS and PSIS, respectively). The pelvic origin was halfway between the two ASIS markers, the y axis was a vector from right to left ASIS, the x axis was a vector from halfway between the two PSIS markers to the origin, and the z axis was perpendicular to this xy plane. Pelvic angular position with respect to the global (i.e., laboratory) coordinate system was calculated using a flexion/extension, ab/adduction, in/external Cardan sequence of rotation (Fig. 2). The trunk was defined by three markers (one on cervical vertebra 7 (C7) and two at the level of the sternoclavicular joints). The trunk origin was defined as halfway between the two sternoclavicular joint markers, the y axis was defined as a vector from the right to left sternoclavicular marker, the x axis was defined as a vector from C7 to the origin, and the z axis perpendicular to this xy plane. Trunk angular position was defined with respect to the pelvis. Typically developing reference values based on this marker set and definition indicate that pelvic tilt values *greater* than 11.6° and trunk tilt values *less* than 21.2° represent lumbar lordosis that exceeds the 50th percentile (i.e., more lumbar lordosis; Table 1). Pelvic tilt and trunk tilt angles were time-normalized, and then the curves were averaged across three barefoot walking trials at self-selected

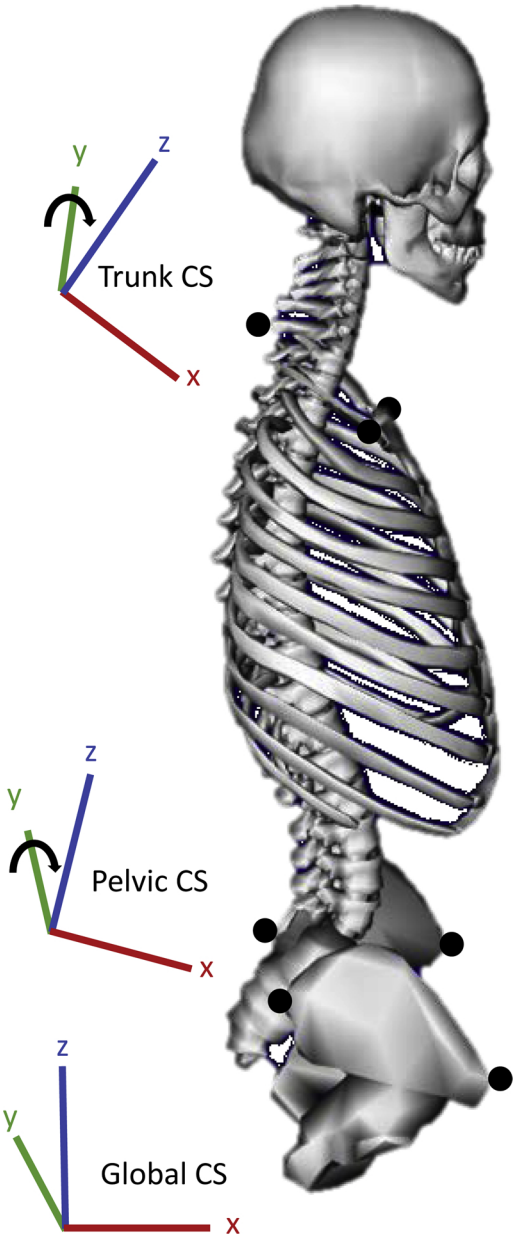

Fig. 2. Reflective markers placed on the individuals to define the pelvis and trunk segments are shown as black dots. Pelvic angular position was defined as the pelvic coordinate system (CS) relative to the global (laboratory) CS. Trunk angular position was defined as the trunk CS relative to the pelvic CS.

6. **Indicate the location of the pain and when it occurs. Please check all that apply:**

	R=Right	**L**=Left	**B**=Both	**Beginning or End of Day**	**Walking Short Distances**	**Prolonged Walking**	**Standing**	**Stairs or Uneven Terrain**	**Constant Pain Not Activity Related**
Back	lower	upper	both	O	O	O	O	O	O
Hips	☐ R	☐ L	☐ B	O	O	O	O	O	O
Knees	☐ R	☐ L	☐ B	O	O	O	O	O	O
Ankles	☐ R	☐ L	☐ B	O	O	O	O	O	O
Feet	☐ R	☐ L	☐ B	O	O	O	O	O	O
Other :				O	O	O	O	O	O
Please describe:									

Fig. 1. Back pain prevalence question on the Gillette Functional Assessment Questionnaire. The respondent is asked to indicate the body segment or joint in which pain is occurring, the laterality of the pain, and when/during what circumstances the pain is experienced.

Table 1
Participant demographics and mean pelvic and trunk tilt averaged over the gait cycle (mean (standard deviation) [min-max], unless noted).

			GMFCS level (%)*								
Group	n (%)	Age (years)	I	II	III	IV	Unk	Assistive Device, n(%)	Speed (m/s)	Mean Pelvic Tilt (°)	Mean Trunk Tilt (°)^
No back pain	595 (84.4%)	11.7(6.4) [3.5–57.0]	30.1	33.5	29.6	4.0	2.8	204 (34.3%)	0.85 (0.30) [0.10–1.66]	19.3(8.1) [−14.6 to 43.0]	17.3(12.9) [−40.1 to 60.5]
Back pain	105 (14.9%)	17.0(10.1) [3.5–60.3]	30.5	30.5	26.7	1.0	11.4	38 (36.2%)	0.84 (0.31) [0.10–1.41]	21.7(7.9) [5.7 to 39.3]	17.1(13.6) [−16.1 to 55.1]
Typically developing reference										11.6(4.9)	21.2(9.2)

GMFCS: Gross Motor Functional Classification System. Unk: unknown. Pelvic tilt values *greater* than 11.6° and trunk tilt values *less* than 21.2° represent lumbar lordosis that exceeds the 50th percentile compared to typically developing (i.e., more lumbar lordosis).

* GMFCS has not been validated on adults.

^ Trunk data were missing for 4 participants.

speed. Pelvic and trunk tilt were averaged across the entire gait cycle from this average curve.

3. Statistical analysis

Because assistive device use has been shown to increase anterior pelvic and trunk tilt [2,44] and pain prevalence increases with age in this population [9,24], a multivariate logistic regression was performed to determine if back pain prevalence increased as mean pelvic tilt became more lordotic after controlling for device use and age. A logistic regression model in which trunk tilt was the pseudo-measure of lordosis was also explored in the Supplemental Material (Table 1). The null hypothesis was rejected when $p < 0.05$. Sensitivity, specificity, and area under the curve (AUC) were calculated to compare model fit. All statistical analyses were performed in Matlab R2017b (Mathworks®, Natick, MA).

4. Results

Demographics of eligible patients reveal that the Back Pain group was older (Table 1) and that most rates of prior surgeries were comparable (Supplemental Fig. 1). Of the 705 patients who met our inclusion criteria, 5 had upper back pain only and were omitted from further analysis. Of the remaining 700 patients, 597 were children (< 18 years old) and 106 were adults. The prevalence of back pain was 11.1% (standard error: 1.3%) in children and 36.8% (standard error: 4.7%) in adults. Common activities related to the occurrence of pain included prolonged walking, beginning/end of the day, and standing (Fig. 3). Averaged across all patients, individuals with CP had more anterior pelvic tilt and more posterior trunk tilt (i.e., more lordosis) than the reference population of typically developing children (Table 1) [45].

Pelvic tilt and age were significant predictors of back pain, but the effects were small (Table 2). For each degree increase in pelvic tilt in gait (i.e., more anterior), the odds of back pain increased approximately 3% (95% confidence interval (CI): 0–6%). For each year increase in age, the odds of back pain increased approximately 8% (95% CI: 5–11%). Walking with an assistive device was not significantly associated with back pain after controlling for the effects of the other predictors. The model predicted the vast majority of patients to not have back pain, and since the prevalence of back pain was relatively low (15.0%), model specificity was very high but sensitivity was low (4.8%). The AUC indicated that the model performed 17.4%-points better than chance. Using trunk tilt as the pseudo-measure of lordosis, only age was a significant predictor of back pain (Supplemental Table 1).

5. Discussion

There appears to be a small association between anterior pelvic tilt during gait and back pain in ambulatory individuals with CP after controlling for device use and age, which supports our hypothesis. The effect of pelvic tilt or trunk tilt on back pain was relatively small since the odds ratio lingered around 1.0. This can be illustrated with an example. Consider a 15 year old independently ambulatory male with a mean pelvic tilt of 20° (8.4° more anterior than the typically developing mean) and trunk tilt of 20° (1.2° more posterior than the typically developing mean). The pelvic tilt model in Table 2 predicts his probability of having low back or general back pain to be 16.5% (95% CI: 12.8–20.2%). The trunk tilt model in Supplemental Table 1 predicts 15.6% (95% CI: 11.9%–19.3%). If that individual underwent a DFEO with PTS and pelvic tilt increased 7° (to 27°) and trunk tilt decreased 5° (to 15°), both indicating a greater degree of lumbar lordosis, the probability of that child having low back or general back pain 1 year later would be 20.9% (95% CI: 15.1%–26.8%) based on the pelvic tilt model and 16.2% (95% CI: 11.7%–20.7%) based on the trunk tilt model. Other scenarios can be imagined using the following equation:

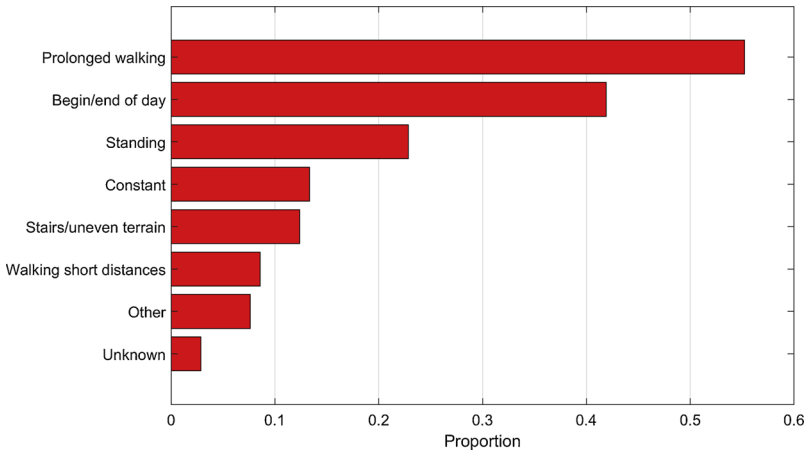

Fig. 3. When/during what circumstances back pain occurred for the 105 individuals with pain. Patients could select more than one activity.

Table 2
Multivariate logistic regression of predictors of back pain and model performance.

Predictors	Coefficient	Standard error	Odds Ratio [95%CI]	p-value	Sensitivity	Specificity	AUC
Intercept	−3.380	0.351	0.034 [0.017–0.068]	< **0.001**	4.8%	99.3%	0.674
Pelvic tilt	0.030	0.015	1.031 [1.002–1.061]	**0.037**			
Age	0.077	0.013	1.080 [1.052–1.109]	< **0.001**			
Assistive Device	−0.123	0.248	0.884 [0.544–1.437]	0.619			

$$\hat{p} = \frac{e^{\beta_o + \beta_1 X_1 + \ldots + \beta_p X_p}}{\left(1 + e^{\beta_o + \beta_1 X_1 + \ldots + \beta_p X_p}\right)}$$

where $\hat{p}$ is the estimated probability of the event occurring (i.e., Back pain), β are the logistic regression coefficients, and X are the input values for the respective predictor variables. Illustratively, whether the statistically significant pelvic tilt or statistically insignificant trunk tilt model is used, the prediction of the probability of having back pain is quite similar.

Back pain prevalence increased with age, which is consistent with another study [46], though the effect was relatively small (odds ratio near 1.0). For example, the above hypothetical 15 year old would increase his probability of having back pain from 16.5% to 17.6% by age 16, with all other factors held constant.

Yeung et al. [2] suggested that assistive devices could be used to help manage back pain in individuals with CP. The current investigation did not support this conclusion as there was no independent association between device use and back pain. However, this investigation and others [2,44] have reported an average 5–7° increase in trunk tilt (i.e., less lordosis) when patients used an assistive device despite anterior pelvic tilt increasing. This would decrease lumbar lordosis, the purported mechanism by which back pain is generated.

The differences in statistical analyses between this study and Harada et al. [24] preclude exact comparison, but our results show a weaker association of dynamic pelvic tilt and back pain. The small effect size observed here is more consistent with others who have shown a lack of relationship between pelvic tilt (in standing) and LBP in typically developing adults [13,18,19]. One reason for the weak (pelvic tilt) or null (trunk tilt) effects could be that the true association of pelvic and trunk tilt with back pain is mitigated by measurement error specific to marker placement. The calculation of pelvic tilt is sensitive to superior/inferior placement of the reflective markers on the anterior superior iliac spines. As such, the standard error of measurement for pelvic tilt is almost 4° (summary by McGinley et al. [47]). Trunk tilt would be affected similarly. It is likely that radiographic measurements of lumbar lordosis in Harada et al. [24] have a smaller standard error of measurement which may explain the stronger association with back pain.

Age of participants also differed from that of Harada et al. [24] (mean age: 12.6 vs. 20.1 years), which may partly explain why their LBP prevalence was higher (44%) than the current study (15.0%). Back pain prevalence data in the current study are more consistent with Alriksson-Schmitdt & Hagglund [9] (9.3%, ages 1–14) and Doralp and Bartlett [8] (18.7%, mean age 15).

Back pain in this population occurred primarily with prolonged walking, beginning or end of the day, and standing. Since chronic pain decreases physical function in patients with CP [4], having back pain could deter patients from performing these activities. Since adults with CP have a greater risk for developing chronic medical conditions such as asthma, hypertension, emphysema, and stroke [6], decreased mobility can contribute to the development of such medical comorbidities [48].

Many of the patients within this study had prior non-spinal surgeries. In general, the Back Pain group tended to have more surgeries than the No Back Pain group. This does not seem to be a result of motor involvement since GMFCS level tended to be higher (i.e. greater impairment) in the No Back Pain group. Rather, it may be due to the Back Pain groups being older, thus having had more time to have undergone interventions.

Based on the results of this study, increased anterior pelvic tilt is weakly associated with back pain in individuals with CP. Our study was not designed to ascertain if it is a causal relationship, but if it is, prospective investigations could determine if the expected increase in anterior pelvic tilt after flexed knee gait surgery or selective dorsal rhizotomy leads to increased back pain in adulthood [25–31,33,35–38,49–51]. Alternatively, some studies have suggested that pelvic tilt does not change after flexed knee gait surgeries if certain concomitant surgeries are omitted or included [31,33,50], though all studies had small sample sizes (≤20 patients per group) which precluded the ability to detect anything less than very large effect sizes.

Limitations of this study should be noted. First, its retrospective, cross-sectional design is prone to sampling bias and does not allow us to determine if observed associations are spurious or causal. Second, the psychometric properties of the question that quantified back pain have not been determined, and we cannot decipher whether pain was chronic or transient, nor can we quantify its intensity. Third, the trunk is not a rigid body, but it was considered such in order to calculate the joint angle between the trunk and pelvis (i.e., trunk tilt). Finally, this sample was relatively young. A more representative older adult population may reveal much more distinction between groups and the pseudo-measures of lumbar lordosis.

6. Conclusion

Back pain was more prevalent in adults versus children in a large sample of ambulatory individuals with CP who had a gait analysis, but it was only weakly related to increased anterior pelvic tilt during gait. Future studies are needed to determine if these ostensibly weak associations cause back pain in this population.

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Declaration of Competing Interest

The authors have no conflicts of interest to disclose regarding this manuscript.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.gaitpost.2019.08.011.

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