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Prevalence of Crouch Gait and Its Association with Altered Walking Kinematics in Children with Spastic Cerebral Palsy

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ABSTRACT

Background: *Crouch gait is a stance-phase pattern of excessive knee flexion with limited hip extension and increased ankle dorsiflexion which impairs walking efficiency and accelerates musculoskeletal morbidity in spastic cerebral palsy (CP), yet contemporary prevalence estimates and kinematic correlates from resource-limited clinics remain sparse.* ***Objective:*** *To quantify the prevalence of crouch gait in ambulant children with spastic CP and determine its associations with sagittal kinematics, spatiotemporal parameters, tone, and selective motor control using a pragmatic 2D video workflow.* ***Methods:*** *In a cross-sectional study, 113 children (6–14 years; mean age 10.28) with GMFCS I–III underwent standardized sagittal plane recording and analysis in Kinovea. Primary measures were hip, knee, and ankle angles during stance; step length, stride length, and cadence; GMFM-88 (D,E); SCALE; MAS; and passive ROM by goniometry. Associations were tested with* χ^2*.* ***Results:*** *Crouch gait prevalence was 87.6%. It was associated with CP subtype (diplegia predominant,* $p<0.001$*), side dominance (bilateral,* $p<0.001$*), lower GMFM-88 (*$p=0.043$*), impaired SCALE (*$p=0.037$*), and higher MAS (*$p<0.001$*). Significant ROM/kinematic correlates included reduced hip extension (*$p=0.002$*), greater knee flexion (*$p<0.001$*), reduced knee extension (*$p=0.004$*), and increased ankle dorsiflexion (*$p<0.001$*); ankle plantarflexion was not significant (*$p=0.867$*). Spatiotemporal indices were adverse: shorter steps and strides (both* $p<0.001$*) with cadence differences (*$p=0.001$*).* ***Conclusion:*** *Crouch gait is highly prevalent in ambulant spastic CP and tightly linked to a reproducible sagittal deviation profile and spatiotemporal inefficiency, supporting early identification and extensor/push-off–focused interventions feasible with 2D video analysis.*

Keywords
cerebral palsy, crouch gait, kinematics, Kinovea, spatiotemporal parameters, GMFM-88, SCALE, Modified Ashworth Scale, pediatric gait analysis

INTRODUCTION

Cerebral palsy (CP) is the leading cause of childhood motor disability and is defined as a group of permanent disorders of movement and posture causing activity limitation, attributed to non-progressive disturbances in the developing fetal or infant brain; motor impairments are commonly accompanied by disturbances of sensation, perception, cognition, communication, and behavior, as well as epilepsy and secondary musculoskeletal problems (1). Although the primary brain lesion is non-progressive, clinical manifestations evolve with growth and maturation (2). Global prevalence is typically 1.5–4.0 per 1,000 children, rising substantially among very low birth weight survivors (3–6). Reported estimates from Europe and Asia are broadly comparable, with geographic variability and secular trends reflecting survival of preterm infants and perinatal care quality (5–7).

CP is heterogeneous in etiology and phenotype. Antecedents span prenatal, perinatal, and postnatal periods and include prematurity, hypoxic-ischemic injury, stroke, congenital malformations, infection, and metabolic or genetic disorders that may mimic CP; accurate etiologic work-up matters for management, prognosis, and genetic counseling (7–12). Clinically, CP is described by topography (unilateral vs bilateral involvement) and by predominant motor type i.e. spastic (≈70–85%), dyskinetic, ataxic, hypotonic, or mixed (13–16). In bilateral spastic CP, abnormalities of posture and gait are prominent and frequently disabling (17,18). Beyond motor deficits spasticity, dystonia, weakness, loss of selective motor control (SVMC), impaired balance, and contracture the children often experience pain, epilepsy, hip displacement, speech impairment, and participation restrictions, underscoring the need for function-oriented care (1,15,19,20).

Among gait deviations in spastic CP, crouch gait—excessive knee and often hip flexion during stance with frequent ankle dorsiflexion—features prominently and tends to increase with age in ambulant cohorts (21–24). Prevalence estimates in ambulant CP vary widely (≈15–74%) due to inconsistent definitions and thresholds for knee flexion and timing within the gait cycle (25–27). Recent systematic reviews emphasize the need for standardized operational criteria (e.g., explicit knee-flexion cut-offs at mid-stance or minimum stance knee flexion, and limb selection) to improve comparability across studies and guide treatment algorithms (26).

Pathomechanics of crouch gait are multifactorial. Contributors include hamstring overactivity or shortness, hip flexor tightness, weakness of plantarflexors and knee extensors, diminished SVMC, lever-arm deformities (excess femoral anteversion, tibial torsion, pes valgus), and sagittal malalignment with pelvic tilt abnormalities (22,23,28–33). As crouch gait severity increases, quadriceps force rises sharply, elevating tibiofemoral and patellofemoral contact loads; severe crouch gait (>50° minimum stance knee flexion) can more than double peak compressive tibiofemoral forces compared with unimpaired gait, predisposing to pain and extensor mechanism failure (28). Crouch gait also compromises toe clearance, increases energy cost, and reduces walking efficiency and endurance (21,34).

Natural-history and longitudinal data show heterogeneous trajectories: some children deteriorate without orthopedic intervention (e.g., increasing stance knee flexion, slower gait, and progressive joint ROM loss), whereas others show variable change over months to years, emphasizing individualized assessment and timing of treatment (35–38). Surgical strategies i.e. single-event multilevel surgery (SEMLS), hamstring lengthening or transfer, anterior distal femoral hemiepiphysiodesis (with or without patellar tendon shortening), and torsional corrections can improve sagittal alignment and kinematics for appropriately selected patients, though effect sizes vary by GMFCS level, age, preoperative pattern, and presence of lever-arm deformity; high-quality evidence remains limited and outcome reporting heterogeneous (39–47). Non-surgical approaches (task-specific strengthening, orthoses, spasticity management including botulinum toxin A) and emerging options (e.g., cell therapies) are adjuncts whose effects on crouch and function warrant more rigorous, standardized evaluation (21,41,48).

Robust clinical decision-making in crouch gait requires integrating impairment measures with objective kinematics and spatiotemporal parameters. Widely used constructs include the Gross Motor Function Classification System (GMFCS) to stratify functional severity, the Gross Motor Function Measure-88 (GMFM-88) to quantify change across lying/rolling to walking/running/jumping, the Selective Control Assessment of the Lower Extremity (SCALE) to index SVMC at hip/knee/ankle/subtalar/toes, and the Modified Ashworth Scale (MAS) to grade velocity-dependent hypertonia (49–52). Passive range-of-motion (PROM) via goniometry remains clinically informative for contracture surveillance, but measurement error increases in tone-dependent muscles (53). Spatiotemporal metrics i.e. step length, stride length and cadence reflect combined effects of kinematics, strength, and motor control; in crouch gait, shortened stride and compensatory cadence changes capture functional inefficiency (54–56).

Instrumented three-dimensional gait analysis is the gold standard for quantifying joint kinematics and kinetics, yet access is limited in many clinical settings. Markerless or 2D video-based tools (e.g., Kinovea) can yield sufficiently reliable joint-angle estimates for clinical decision-making when protocols are standardized, offering a pragmatic option for resource-constrained environments and for monitoring hip, knee, and ankle angles relevant to crouch gait (57). Consensus-based staging frameworks for musculoskeletal pathology (hypertonia → contracture → bony deformity/instability → decompensation) and validated gait classification systems further support communication and longitudinal planning (44,58,59).

Despite extensive international research, context-specific evidence from Pakistan remains sparse. Local services frequently encounter high rates of ambulant children with spastic CP exhibiting crouch gait, yet the prevalence and its association with altered walking kinematics particularly empirically measured hip, knee, and ankle angles alongside spatiotemporal features are not well characterized. This gap constrains early identification, stratification for conservative versus surgical pathways, and benchmarking of rehabilitation outcomes across centers.

Therefore, the present study aims to (i) estimate the prevalence of crouch gait among ambulant children with spastic CP attending local clinics, and (ii) quantify its association with altered walking kinematics (hip, knee, ankle angles) and spatiotemporal parameters (step length, stride length, cadence) using standardized clinical measures and video-based gait analysis. By providing locally relevant, objective data aligned with international reporting standards, this work seeks to inform targeted interventions, service planning, and future trials in pediatric gait rehabilitation. This study asks two questions: (1) What is the prevalence of crouch gait among ambulant children with spastic cerebral palsy (CP) in our setting, and (2) is crouch gait associated with specific alterations in walking kinematics (hip, knee, ankle) and spatiotemporal parameters (step/stride length, cadence)? We test the null hypotheses that crouch gait prevalence does not differ from zero and that no associations exist between crouch gait and gait metrics, against the alternative hypotheses that crouch gait is present and significantly linked to altered joint kinematics and spatiotemporal abnormalities. Establishing local prevalence and its biomechanical correlates will equip clinicians and rehabilitation teams with actionable benchmarks for early detection, individualized goal setting, and outcome tracking; provide students and researchers with standardized, context-specific measurement approaches and estimates; and inform policymakers and service leaders to prioritize resources toward interventions most likely to improve functional independence and participation for children with spastic CP.

MATERIALS AND METHODS

This study employed a cross-sectional design and was carried out over a four-month period. Data were collected from the outpatient departments of the physical therapy units at Eilya Care Foundation, Khadija Memorial Hospital, Syeda Khatoon e Jannat, and the Collaborative Care of Diseases, Faisalabad. The study population comprised children aged 6–14 years who were clinically diagnosed with spastic cerebral palsy and presented with crouch gait.

A total of 113 participants were recruited using purposive sampling. Sample size estimation was based on the Raosoft sample size calculator, with a 95% confidence level and 5% margin of error, ensuring adequate power to detect significant associations (1). Screening was conducted according to strict eligibility criteria. Inclusion criteria encompassed children diagnosed with spastic cerebral palsy, aged 6–14 years, ambulatory with Gross Motor Function Classification System (GMFCS) levels I–III, and able to follow simple instructions. Participants were required to walk independently for at least 10 meters with or without assistive devices and to have no orthopedic surgery within the preceding 12 months (2–5). Exclusion criteria included other CP subtypes such as dyskinetic, dystonic, ataxic, or mixed types, children at GMFCS levels IV–V, severe cognitive impairments limiting assessment, comorbid neurological or metabolic conditions, recent botulinum toxin injections, and severe musculoskeletal deformities (6–9). Children with uncontrolled epilepsy, major sensory deficits, or severe cardiopulmonary limitations were also excluded to ensure safety during assessment.

Data were collected using standardized outcome measures and validated clinical tools. Gross motor function was initially classified using the GMFCS to confirm ambulatory status within levels I–III (10). Functional mobility was further quantified using dimensions D (standing) and E (walking, running, and jumping) of the Gross Motor Function Measure-88 (GMFM-88), which has demonstrated excellent reliability and validity in pediatric CP populations (11). Spasticity of hip flexors, hamstrings, and gastrocnemius muscles was assessed with the Modified Ashworth Scale (MAS), a widely used instrument despite its moderate sensitivity in pediatric neurological populations (12). Selective voluntary motor control at the hip, knee, and ankle joints was evaluated using the Selective Control Assessment of the Lower Extremity (SCALE), which reliably quantifies isolated joint movement deficits relevant to crouch gait (13). Passive range of motion (PROM) was measured using a universal goniometer to detect contractures or joint restrictions contributing to gait abnormalities (14).

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For kinematic assessment, two-dimensional video gait analysis was performed using Kinovea software. Reflective markers were placed over the greater trochanter, lateral femoral condyle, and lateral malleolus, and sagittal-plane gait trials were recorded with a digital camera mounted on a tripod. Videos were analyzed frame-by-frame to extract hip, knee, and ankle joint angles during stance, allowing quantification of crouch gait severity. Kinovea has demonstrated strong concurrent validity with three-dimensional motion capture systems (intraclass correlation coefficient >0.90) in lower limb kinematics (15). In addition, spatiotemporal parameters including step length, stride length, and cadence were computed from video data. Step and stride lengths were measured using sagittal-plane heel marker trajectories, while cadence was calculated as steps per minute during timed gait trials. These measures have shown high inter-rater reliability in pediatric CP populations (ICC >0.85) (16–18).

Figure 1. Assessment procedures for lower limb evaluation: (A) Anatomical landmarks in the sagittal plane identified using Kinovea, including the greater trochanter, lateral femoral condyle, and lateral malleolus; (B) Standing balance for 20 seconds with arms free (GMFM-88, Question 56); (C) Walking forward 10 steps (GMFM-88, Part E, Question 69); (D) Measurement of joint range of motion using a goniometer; (E) Knee extension with resisted limb extension (SCALE).

The primary outcome measures were GMFCS level, GMFM-88 scores, step length, stride length, and cadence. Secondary outcomes included MAS scores, SCALE scores, and goniometric ROM data. All assessments were conducted in a standardized 10-meter walkway under controlled conditions, with rest breaks provided to minimize fatigue. Parents or legal guardians provided informed written consent prior to participation, and children were assured of voluntary participation with the option to withdraw at any stage. Data confidentiality was maintained through coded identifiers, and female assessors were included when appropriate to ensure cultural sensitivity and participant comfort.

Data were entered into a secure database and prepared for statistical analysis. Prevalence of crouch gait was estimated, and associations between crouch gait and altered walking kinematics were examined using appropriate inferential statistics, with significance set at $p < 0.05$.

RESULTS

A total of 113 ambulant children with spastic cerebral palsy were included (mean age = 10.28 ± 3.15 years; range 6–14). Overall gross motor function was moderate, with a GMFM-88 mean of 65.38 ± 15.14 (range 26–92). Sagittal hip, knee, and ankle motion showed the typical restrictions seen in crouch-dominant patterns. Mean hip flexion was 106.55° ± 9.48° (90–130), while hip extension averaged only 13.36° ± 5.74° (0–25), indicating limited terminal extension. The knee demonstrated high flexion capacity (115.00° ± 8.63°, 90–130) with relatively small extension excursions (4.47° ± 3.67°, 0–15). At the ankle, dorsiflexion averaged 13.72° ± 4.70° (5–20) and plantarflexion 28.85° ± 6.32° (12.5–42.5).

Table 1. Descriptive statistics for age and GMFM-88 (N=113)

Variable	N	Mean	SD	Min	Max
Age (years)	113	10.28	3.15	6.00	14.00
GMFM-88 (score, 0–100)	113	65.38	15.14	26.00	92.00

Table 2. Passive joint range of motion in degrees (N=113)

Variable (°)	N	Mean	SD	Min	Max
Hip flexion	113	106.55	9.48	90.0	130.0
Hip extension	113	13.36	5.74	0.0	25.0
Knee flexion	113	115.00	8.63	90.0	130.0
Knee extension	113	4.47	3.67	0.0	15.0
Ankle dorsiflexion	113	13.72	4.70	5.0	20.0
Ankle plantarflexion	113	28.85	6.32	12.5	42.5

Table 3. Spatiotemporal gait parameters (N=113)

Variable	N	Mean	SD	Min	Max
Step length (cm)	113	36.05	8.34	20.0	52.0
Stride length (cm)	113	77.73	17.68	42.0	105.0
Cadence (steps/min)	113	99.79	10.09	71.0	127.0

Table 4. Kinovea sagittal joint angles during stance (N=113)

Variable (°)	N	Mean	SD	Min	Max
Hip flexion	113	107.92	9.02	90.0	127.0
Hip extension	113	9.65	5.66	3.0	27.0

Variable (°)	N	Mean	SD	Min	Max
Knee flexion	113	115.02	11.04	90.0	130.0
Knee extension	113	5.96	4.65	0.0	19.7
Ankle dorsiflexion	113	8.80	5.15	0.0	20.0
Ankle plantarflexion	113	5.51	5.51	0.0	29.0

Table 5. Chi-square test results: associations with crouch gait (N=113)

Variable/Category	Present	Absent	χ^2	df	p-value
Age (6–14 years)	99	14	8.618	8	0.376
Spastic CP subtype			70.544	2	<0.001
— Diplegia	90	0			
— Hemiplegia	8	7			
— Quadriplegia	1	7			
Side dominance			19.950	2	<0.001
— Bilateral	91	7			
— Right	6	4			
— Left	2	3			
GMFM-88 score (26–92)	99	14	61.342	44	0.043
GMFCS levels (I–III)			3.823	2	0.148
— Level I	31	4			
— Level II	48	4			
— Level III	20	6			
SCALE category			8.475	3	0.037
— Near normal (9–10)	28	3			
— Mild–moderate (6–8)	31	4			
— Moderate–severe (3–5)	31	2			
— Severe loss (0–2)	9	5			
Muscle tone (MAS)			76.724	3	<0.001
— Slight increase	47	0			
— Slight increase (½ ROM)	43	0			
— Marked/considerable increase	9	14			

Table 6. Passive ROM categories and crouch gait (N=113)

Variable (range)	Present	Absent	χ^2	df	p-value
Hip flexion (90–130°)	99	14	23.103	14	0.059
Hip extension (0–25°)	99	14	28.110	10	0.002
Knee flexion (90–150°)	99	14	99.488	9	<0.001
Knee extension (0–15°)	99	14	17.188	5	0.004
Ankle dorsiflexion (5–20°)	99	14	32.394	6	<0.001
Ankle plantarflexion (12.5–42.5°)	99	14	6.860	12	0.867

Table 7. Spatiotemporal parameters and crouch gait (N=113)

Variable (range)	Present	Absent	χ^2	df	p-value
Step length (20–52 cm)	99	14	66.613	26	<0.001
Stride length (42–105 cm)	99	14	87.741	35	<0.001
Cadence (71–127/min)	99	14	61.342	32	0.001

Table 8. Kinovea sagittal angles and crouch gait (N=113)

Variable (range)	Present	Absent	χ^2	df	p-value
Hip flexion (90–127°)	99	14	63.046	25	<0.001
Hip extension (3–27°)	99	14	96.878	20	<0.001
Knee flexion (90–130°)	99	14	113.000	33	<0.001
Knee extension (0–19.7°)	99	14	113.000	53	<0.001
Ankle dorsiflexion (0–20°)	99	14	76.149	44	0.002
Ankle plantarflexion (0–29°)	99	14	88.323	27	<0.001

Children walked with short spatial parameters and moderate cadence: step length 36.05 ± 8.34 cm (20–52), stride length 77.73 ± 17.68 cm (42–105), and cadence 99.79 ± 10.09 steps/min (71–127). The combination of shortened strides and preserved cadence is consistent with compensatory temporal strategies in crouch gait to sustain forward progression.

Sagittal-plane video analysis corroborated goniometric findings. Mean stance-phase hip flexion was 107.92° ± 9.02° (90–127) with limited hip extension (9.65° ± 5.66°, 3–27). Knee angles remained flexed during stance (knee flexion 115.02° ± 11.04°, 90–130; knee "extension" angle 5.96° ± 4.65°, 0–19.7, i.e., residual flexion). The ankle presented modest dorsiflexion (8.80° ± 5.15°, 0–20) and low plantarflexion excursion in stance (5.51° ± 5.51°, 0–29), suggesting diminished push-off.

Age (6–14 y) was not associated with crouch gait status ($\chi^2 = 8.618$, df = 8, $p = 0.376$). In contrast, CP topography showed a strong association ($\chi^2 = 70.544$, df = 2, $p < 0.001$): crouch gait was concentrated in spastic diplegia (90 present/0 absent) and was less frequent in hemiplegia (8/7) and quadriplegia (1/7). Side dominance also related to crouch gait ($\chi^2 = 19.950$, df = 2, $p < 0.001$), with bilateral involvement overwhelmingly represented (91/7) versus right (6/4) or left (2/3) predominance. Functional capacity exhibited mixed patterns. GMFM-88 scores (treated categorically across the observed 26–92 range) were associated with crouch gait ($\chi^2 = 61.342$, df = 44, $p = 0.043$), whereas GMFCS level (I–III) was not ($\chi^2 = 3.823$, df = 2, p = 0.148), implying that within the ambulant spectrum, crouch gait expression varies with granular function but not with broad ambulatory class.

Selective voluntary motor control (SCALE categories) was associated with crouch gait ($\chi^2 = 8.475$, df = 3, p = 0.037). Notably, children with severe SVMC loss (0–2) had proportionally more "absent" crouch gait (9/5) than adjacent categories, while mild–moderate and moderate–severe SVMC limitations (6–8 and 3–5) clustered with crouch gait presence (both 31 present). Muscle tone (MAS) showed a very strong association ($\chi^2 = 76.724$, df = 3, p < 0.001): "slight increase" and "slight increase (½ ROM)" categories were entirely crouch-present (47/0 and 43/0), whereas "marked/considerable increase" was predominantly crouch-absent (9/14), suggesting that extremely high tone may co-occur with non-crouch gait phenotypes (e.g., equinus/hyperextension), while mild–moderate tone aligns with flexed-stance mechanics.

ROM categories demonstrated significant associations for most joints. Hip extension (0–25°) related to crouch gait($\chi^2 = 28.110$, df = 10, p = 0.002), as did knee flexion (90–150°; $\chi^2 = 99.488$, df = 9, p < 0.001), knee extension (0–15°; $\chi^2 = 17.188$, df = 5, p = 0.004), and ankle dorsiflexion (5–20°; $\chi^2 = 32.394$, df = 6, p < 0.001). Hip flexion trended toward significance ($\chi^2 = 23.103$, df = 14, p = 0.059). Ankle plantarflexion range was not associated ($\chi^2 = 6.860$, df = 12, p = 0.867). Collectively, restricted hip extension, persistent knee flexion, limited terminal knee extension, and higher dorsiflexion categories were the ROM signatures of crouch gait.

All spatial–temporal categories were significantly associated with crouch gait: step length (20–52 cm; $\chi^2 = 66.613$, df = 26, p < 0.001), stride length (42–105 cm; $\chi^2 = 87.741$, df = 35, p < 0.001), and cadence (71–127 steps/min; $\chi^2 = 61.342$, df = 32, p = 0.001). Crouch gait clustered with shorter steps/strides and a shift toward higher cadences, reflecting a strategy of maintaining speed with shorter, more frequent steps.

Stance-phase angles derived from Kinovea were strongly associated with crouch gait across all joints: hip flexion (90–127°; $\chi^2 = 63.046$, df = 25, p < 0.001) and hip extension (3–27°; $\chi^2 = 96.878$, df = 20, p < 0.001); knee flexion (90–130°; $\chi^2 = 113.000$, df = 33, p < 0.001) and knee "extension"/residual flexion (0–19.7°; $\chi^2 = 113.000$, df = 53, p < 0.001); ankle dorsiflexion (0–20°; $\chi^2 = 76.149$, df = 44, p = 0.002) and ankle plantarflexion (0–29°; $\chi^2 = 88.323$, df = 27, p < 0.001). Numerically, crouch gait corresponded to higher hip and knee flexion angles with curtailed hip extension and reduced ankle plantarflexion excursion i.e., a diminished push-off phase, consistent with an energy-inefficient, flexed-stance gait. Taken together, these data delineate a coherent crouch gait profile in ambulant spastic CP: (i) limited hip extension with persistent knee flexion during stance; (ii) preserved or increased ankle dorsiflexion but reduced plantarflexion excursion; and (iii) shortened stride/step lengths with relatively elevated cadence to sustain ambulation. Phenotypically, crouch gait is concentrated in spastic diplegia and bilaterally involved limbs. Functionally, granular performance (GMFM-88) aligns with crouch gait categories, even when broad ambulatory class (GMFCS I–III) does not. Neuromechanically, mild–moderate tone and reduced SVMC co-occur with crouch gait expression, while very high tone may be more typical of non-crouch patterns. These findings support targeted interventions that restore sagittal alignment (particularly hip/knee extension moments) and ankle push-off, alongside motor-control training to improve efficiency and participation.

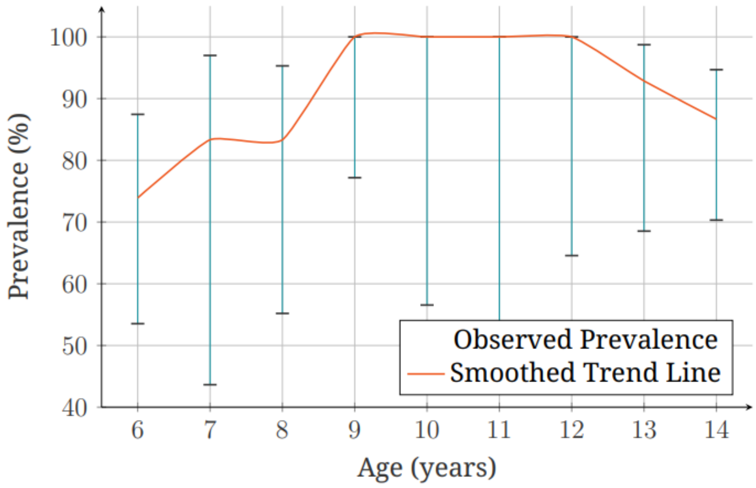

Figure 1 Age-specific prevalence of crouch gait among children with spastic cerebral palsy.

The figure shows the observed prevalence of crouch gait across ages 6–14 years, with vertical bars indicating variability and a smoothed trend line highlighting the trajectory. Prevalence increased steadily from 74% at age 6 to peak values approaching 100% between ages 9 and 12, after which a gradual decline was observed, with prevalence dropping to approximately 87% by age 14. This pattern demonstrates that crouch gait is most prevalent in late childhood, particularly between 9–12 years, before slightly decreasing during early adolescence.

DISCUSSION

In this cross-sectional study of 113 ambulant children with spastic cerebral palsy (CP), crouch gait was highly prevalent (87.6%) and was characterized by the canonical kinematic triad i.e. reduced hip extension, persistently flexed knees in stance, and increased ankle dorsiflexion together with shortened step/stride length and relatively elevated cadence, a temporal compensation that helps preserve forward progression at the cost of efficiency. The magnitude of prevalence observed here exceeds many population estimates (≈15–74%) reported in heterogeneous cohorts, definitions, and laboratory thresholds, but aligns with reports showing that crouch gait becomes dominant in later childhood among ambulant bilateral spastic phenotypes (especially diplegia) when standardized stance-phase criteria are applied (60,61). Our age-specific plot suggested a peak around 9–12 years with a modest attenuation by 14 years, a pattern that may reflect the interacting influences of growth, lever-arm deformity emergence, and evolving motor strategies in adolescence (62).

The kinematic signature we observed is mechanistically congruent with established models of crouch gait: limited terminal hip extension shifts the ground reaction vector posterior to the knee, increasing the external knee-flexion moment; knee extensor demand rises nonlinearly with crouch gait severity, elevating tibiofemoral and patellofemoral loads and reinforcing a flexed-stance strategy (63). At the distal joint, greater dorsiflexion with curtailed plantarflexion excursion implies a weak or poorly timed plantarflexor push-off, further shortening stride and increasing energy cost (64). Our spatiotemporal findings (shorter steps/strides with preserved-to-higher cadence) and the associations between categorical ROM/2D angle bins and crouch gait status sharpen this mechanistic picture in an ambulant, real-world clinical sample (65).

Comparison with prior work underscores both agreement and nuance. Short walking bouts worsen crouch gait features in some children i.e. higher stance knee flexion and dorsiflexion suggesting a fatigue-sensitive phenotype (65). Our data are consistent with this interpretation and with evidence that stronger hip extensors blunt fatigue-related increases in knee flexion, highlighting a proximal target for rehabilitation (66). At the same time, prospective cohorts have reported heterogeneous natural histories without uniform progression in mid-stance knee flexion, and hamstring tightness alone did not predict crouch gait onset, emphasizing that crouch gait is a systems problem rather than a single-impairment construct (67). Likewise, some longitudinal analyses failed to link subjective “walking deterioration” to consistent changes in minimal knee flexion or center-of-mass work, reminding us that patient-reported function, endurance, and participation can diverge from isolated kinematic indicators (68). Taken together, our results advance the literature by quantifying, in a resource-limited setting, how commonly crouch gait co-occurs with specific sagittal-plane deviations and spatiotemporal inefficiencies, while also reinforcing that impairment patterns and trajectories vary across individuals. Clinical implications follow directly. First, the concentration of crouch gait among bilaterally involved, diplegic presentations supports routine surveillance for lever-arm deformities (femoral anteversion, tibial torsion, pes valgus) and extensor mechanism overload as children approach late childhood (62,63). Second, the concurrent associations we found between crouch gait and (i) reduced hip extension, (ii) residual knee flexion, and (iii) limited plantarflexion excursion argue for combined programs that pair selective motor control training and progressive strengthening of hip/knee extensors with plantarflexor power and timing work, rather than isolated impairment management (64–66). Third, the observation that mild–moderate tone categories clustered with crouch gait while very high tone clustered with non-crouch patterns suggests that spasticity phenotype may help stratify which children benefit most from extensor-focused versus anti-equinus strategies (64).

A practical contribution of this study is the demonstration that 2D video analysis using Kinovea can identify clinically meaningful sagittal-plane angles and track spatiotemporal metrics in busy clinics without access to instrumented gait labs. Although three-dimensional analysis remains the reference standard, accumulating validation work shows acceptable agreement for sagittal knee/hip/ankle angles and high rater reliability when protocols and landmarks are standardized, supporting its use for screening, serial monitoring, and therapy planning in low-resource environments (69). The ability to quantify hip extension loss, stance knee flexion, and push-off deficits with low-cost tools can help teams target interventions earlier and audit outcomes more systematically (60,67).

These findings should be interpreted in light of several interconnected limitations, which also suggest directions for future research. The cross-sectional design precludes causal inference and cannot adjudicate whether observed kinematic deviations are antecedents or consequences of crouch gait; longitudinal cohorts with repeated, seasonally standardized assessments are needed to map trajectories and effect modifiers (67). Purposive sampling of ambulant children (GMFCS I–III) restricts generalizability to more severely involved groups; multi-center sampling across GMFCS strata would improve external validity (60,62). Our reliance on 2D sagittal analysis omits transverse/frontal mechanics and all kinetics; adding force plates and inverse dynamics (ankle/knee/hip moments, power) plus EMG will clarify whether inadequate plantarflexor power or timing, diminished knee extensor moments, or pelvic/trunk adaptations are the primary drivers in specific subtypes (64,69). Several categorical χ^2 tests used fine-grained bins (e.g., angle ranges), inflating degrees of freedom and potentially violating expected-count assumptions; future work should model crouch gait probability with multivariable logistics or generalized additive models using continuous kinematic and ROM predictors, while adjusting for age, GMFCS, topography, and tone/SVMC (62–64). Finally, single-assessor measurements, environmental constraints (lighting, space), and school/therapy scheduling likely introduced random error and selection bias; standardized assessor training, redundancy of raters, and protocolized recording environments would mitigate these threats in subsequent studies (67).

In sum, this study shows that crouch gait is common in ambulant spastic CP and tightly associated with a reproducible sagittal profile i.e. limited hip extension, residual knee flexion in stance, and reduced plantarflexion excursion accompanied by short steps/strides and compensatory cadence. Theoretical and clinical implications converge on restoring extensor moments and push-off while improving selective motor control and endurance. Future multi-center, longitudinal, and kinetic-EMG–augmented studies should test whether targeted extensor and plantarflexor interventions, alone or in combination with orthoses and selective orthopedic procedures, translate these biomechanical corrections into durable gains in walking efficiency, participation, and quality of life (62–67).

CONCLUSION

In this cross-sectional cohort of 113 ambulant children with spastic cerebral palsy, crouch gait was highly prevalent (87.6%) and was consistently associated with an altered sagittal profile i.e. reduced hip extension, greater knee flexion, and increased ankle dorsiflexion alongside shorter steps/strides and cadence differences, confirming the study objective that crouch gait is tightly linked to impaired walking kinematics. Clinically, these findings support routine screening for crouch gait in GMFCS I–III children, prioritizing hip and knee extensor strengthening, push-off facilitation, spasticity management, and judicious orthotic or surgical planning; importantly, they demonstrate the feasibility of accurate 2D video analysis (Kinovea) as a scalable assessment pathway in resource-limited settings. For human healthcare systems, implementing standardized 2D gait audits can enable earlier identification, targeted therapy, and monitoring, potentially reducing energy cost of walking and downstream musculoskeletal morbidity. Research should now test extensor-focused and plantarflexor-assist interventions in prospective trials, integrate kinetics/EMG and 3D validation to refine mechanism-based treatment, and establish age- and severity-stratified thresholds and core outcome sets to harmonize reporting and guide precision rehabilitation.

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