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Gait patterns in hemiplegic cerebral palsy: Is it time for a new classification?☆

Mauro César de Morais Filho [a,*], Marcelo H. Fujino [a], Cátia M. Kawamura [b], José Augusto F. Lopes [c], Laís Przysiada [d], Maria Eduarda Antunes Silva [d]

[a] Pediatric Orthopedic Surgeon, Gait Laboratory and Cerebral Palsy Clinic, AACD, São Paulo, Brazil
[b] Senior Physical Therapist, Gait Laboratory, AACD, São Paulo, Brazil
[c] Engineer, Gait Laboratory, AACD, São Paulo, Brazil
[d] Pediatric Orthopedic Fellow, AACD, São Paulo, Brazil

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ABSTRACT

Background: The Winters, Gage and Hicks classification (WGHC) for spastic hemiplegia has been widely used, despite its limitations. The purpose of this study was to evaluate the reliability of WGHC in large series of cerebral palsy (CP).
Research question: May all hemiplegic CP patients be classified according to WGHC?
Methods: Participants with the diagnosis of spastic hemiplegic CP were identified in gait laboratory database. Only the first gait analysis of each patient was considered, and 983 patients met the inclusion criteria. Individuals with mixed tone (45), other pathologies combined with hemiplegia (11) and previous orthopedic surgeries or botulinum injections within 12 months (395) were excluded. The remaining 532 subjects were classified according to the 4 groups described by WGHC.
Results: 224 (42.1 %) patients were unclassified by WGHC and 4 additional groups were identified: group V (115/21.6 %)-none of the alterations described in WGHC; group VI (76/14.3 %)- WGHC III or IV, but with normal ankle dorsiflexion in stance and swing; group VII (29/5.5 %)- WGHC II, III or IV, but with normal ankle dorsiflexion in swing phase; group VIII (4/0.7 %)-reduction of ankle dorsiflexion in stance and swing phases with increased hip flexion in stance, but with normal knee range of motion. The age in group VI (14.5 years) was higher than other groups ($p < 0.001$). The GDI in group V (76.3) was similar ($p = 0.979$) to group I (73.9) and greater than other groups ($p < 0.001$). The mean pelvic asymmetry (32.7^0) and internal hip rotation (18^0) in group IV were higher than other groups ($p < 0.001$). The higher prevalence of perinatal anoxia (33.3 %) was observed in group VII.
Significance: In the present study, 57.9 % of patients were classified according to WGHC and 4 additional patterns were identified, leading a proposal of update at WGHC.
Level of evidence: III.

1. Introduction

Classification systems for gait pathology in cerebral palsy (CP) have been developed in the last decades to improve clinical diagnosis, decision making processes and communication among multidisciplinary teams [1]. In 1987, Winters, Gage and Hicks described the classification of gait dysfunction in hemiplegic patients based on ankle, knee, and hip alterations in the sagittal plan. However, the transverse plane problems were not addressed and diagnoses other than CP were included [2]. Since then, the Winters, Gage and Hicks classification (WGHC) has been widely used, despite its limitations.

In 2001, Rodda and Graham observed that type 4 hemiplegia was characterized by ankle equinus, flexed stiff knee and flexed hip, as described by WGHC, however they also described the presence of asymmetry in transverse plane, with pelvic retraction and increase of internal hip rotation [3]. Aminian et al. evaluated 71 patients with

☆ The study was conducted at AACD (Association for Assistance to Disable Children), São Paulo, Brazil.
* Corresponding author at: Rua Estado de Israel, 577 – apt 82, Vila Clementino, São Paulo 04022-001, Brazil.
E-mail address: mfmorais@terra.com.br (M.C. de Morais Filho).

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hemiplegic CP and most of them (42 subjects) were classified as type II by WGHC. The authors also noticed that the average internal hip rotation was higher in type IV than in types I and II, but similar in type III [4]. In 2011, Salazar-Torres et al. observed that pelvic retraction was present in 61.5 % of children with unilateral CP in their study. They concluded that the evaluation of gait abnormalities in hemiplegic CP should not be limited to classifications based on sagittal plane kinematics [5].

However, Riad et al. evaluated in 2007 a group of 112 subjects with hemiplegic CP and 23 % of them could not be classified using WGHC, because they had mild deviations from normal values [6]. Moreover, McDowell et al. analyzed 91 children, and they observed that WGHC failed to classify many of them (38/42 %) with milder forms of hemiplegia [7]. Furthermore, Tsitlakidis et al. observed that 17 % of 89 unilateral CP patients were not classifiable using WGHC criteria and most of them (80 %) showed little functional impairment. They also detected those unclassified subjects formed a heterogeneous group and there was a need to distinguish them further [8].

The purpose of this study was to evaluate the reliability of WGHC in a large population of CP subjects and to assess the severity of transverse plane alterations across different gait patterns.

2. Methods

This retrospective cohort study was approved by our institutional review board. We conducted a search in a gait laboratory database, located in a tertiary orthopedic hospital and rehabilitation center, from January 2002 to April 2022, to identify individuals with spastic hemiplegic cerebral palsy, classified as Gross Motor Function Classification System (GMFCS) levels I or II.

The patients were referred to the gait laboratory as part of the treatment decision-making process and came from our rehabilitation center's cerebral palsy clinic, where the diagnosis of hemiplegic CP was made by a pediatric neurology team. Only the first gait analysis of each subject was considered for the study, and 983 of them met the inclusion criteria. Individuals with mixed tone (45), other pathologies combined with hemiplegia (11) and previous orthopedic surgeries or botulinum injections within the 12 months (395) were excluded.

Demographics, past medical history, kinematic data, and Gait Deviation Index (GDI) [9] were collected from the gait laboratory medical records. Kinematic data had been previously collected using reflective markers that were strategically placed on specific anatomical landmarks on each participant, as described by Kabada et al. [10]. An eight-camera Qualisys OQUS300 system (500 Hz) was used for motion capture. Patients were instructed to walk barefoot at a self-selected pace through an eight-meter walkway (26 feet). A minimum of six gait cycles for each assessed lower limb was collected to analyze walking variability during data collection. If the collected trials were consistent and exhibited the same pattern, the mean of these gait cycles was used for the analysis. In the present study, no significant variability among the collected gait cycles for everyone was observed. For this reason, the trial selected for the analysis was the mean of the collected trials. Data was processed using the software Vicon Clinical Manager (VCM, Oxford Metrics, Oxford, UK), according to the technique reported by Davis [11].

The GDI is an index that incorporates how far the patient's gait feature is from the reference "norm" using a singular value decomposition. The reference "norm" is set to 100-points, and each 10-point decrease away from the "normal" gait.

A senior physical therapist and a biomechanical engineer, both with more than 20 years of experience in gait analysis, classified the remaining 532 subjects according to the four groups described by WGHC, following the criteria below:

– Group I: peak of ankle dorsiflexion in swing phase lower than one standard deviation (SD) from normal ($< -5^0$) and peak of ankle dorsiflexion in stance phase inside normal range (13.4^0 +/- 4.8^0).
– Group II: peak of ankle dorsiflexion lower than one SD from normal in swing ($< -5^0$) and stance ($< 8.6^0$) phases.
– Group III: group II criteria plus reduction of knee range of motion (KRM) greater than one SD (KRM $< 43.2^0$).
– Group IV: group III criteria plus reduction of hip range of motion (HRM) more than one SD (HRM $< 30.7^0$).

The pelvic asymmetry (PA) in transverse plane was defined when the difference of mean pelvic rotation on right and left sides was higher than one SD from normal values ($> 8.1^0$). Moreover, a mean internal hip rotation (IHR) more than one SD from normal ($> 10.9^0$) was characterized as an increased IHR.

Demographic and CP etiologic factors, mean IHR and PA, the prevalence of increased IHR and PA, and GDI were analyzed in each group and the results were compared. The ANOVA test was applied for comparison of age, GDI, IHR and PA. The Chi-square test was used to compare the etiologic factors. The Two Proportions Z-Test was used to compare the prevalence of increased IHR and PA and the Tukey's range test for intergroup comparison. The level of significance was set at a p-value < 0.05 for all statistical tests [12].

3. Results

The WGHC criteria was applied to the 532 study participants, and 29 (5.5 %) of them were classified as group I, 105 (19.7 %) as group II, 131 (24.6 %) as group III and 43 (8.1 %) as group IV, however 224 subjects (42.1 %) didn't fit into any of the four WGHC groups (Fig. 1). Four additional patterns were identified in the 224 unclassified WGHC patients (Fig. 2) and they were assembled into the groups below:

– Group V (115 patients/21.6 %): none of the sagittal plane alterations described in WGHC were detected in this group.
– Group VI (76 patients/14.3 %): reduced knee or hip range of motion was observed, but there was no restriction for ankle dorsiflexion in the stance and swing phases.
– Group VII (29 patients/5.5 %): reduction of ankle dorsiflexion in stance or/and reduction of knee range of motion or/and reduction of hip range of motion was present, but with normal ankle dorsiflexion in the swing phase.
– Group VIII (4 patients/0.7 %): There was a reduction of ankle dorsiflexion in the stance and swing phases, plus an increase of hip flexion in the stance phase, but with normal knee range of motion.

Demographics, GDI and kinematics features of all groups is presented in Figs. 1 and 2.

The age (Table 1) in Group VI (14.5 years) was higher than other groups ($p < 0.001$). The GDI (Table 2) in Group V (76.3) was similar ($p = 0.979$) to Group I (74) and greater than other groups ($p < 0.001$). Group IV had the lowest ($p < 0.001$) GDI (39.5).

The prevalence of PA in transverse plane was 51.7 % in Group I, 64.8 % in Group II, 80.2 % in Group III, 93 % in Group IV, 63.9 % in Group V, 72.5 % in Group VI and 65.5 % in Group VII. The PA mean (Table 3) in group IV (32.7^0) was higher than other groups ($p < 0.001$) and Group III showed a greater PA mean (20.3^0) than groups I (10.8^0, $p = 0.003$) and V (13.4^0, $p < 0.001$).

The increased IHR ($>10.9^0$) was seen in 20.7 % of the patients in Group I, 14.3 % in Group II, 46.6 % in Group III, 65.1 % in Group IV, 12.3 % in Group V, 30.4 % in Group VI and 24.1 % in Group VII. Group IV (Table 4) presented a greater IHR mean (18^0) than other groups ($p < 0.001$) and the IHR mean in Group III (9.9^0) was higher than groups I (-1.6^0, $p < 0.001$), II (2.2^0, $p < 0.001$) and V (0.9^0, $p < 0.001$).

In Group VIII, the mean age was 14.7 years and the GDI mean was 46.4. PA was observed in all patients from Group VIII (PA mean: 28.7^0) while 29 % of the patients displayed an increased IHR (IHR mean: 14.9^0). No comparisons were carried out in Group VIII due the small number of patients in this group.

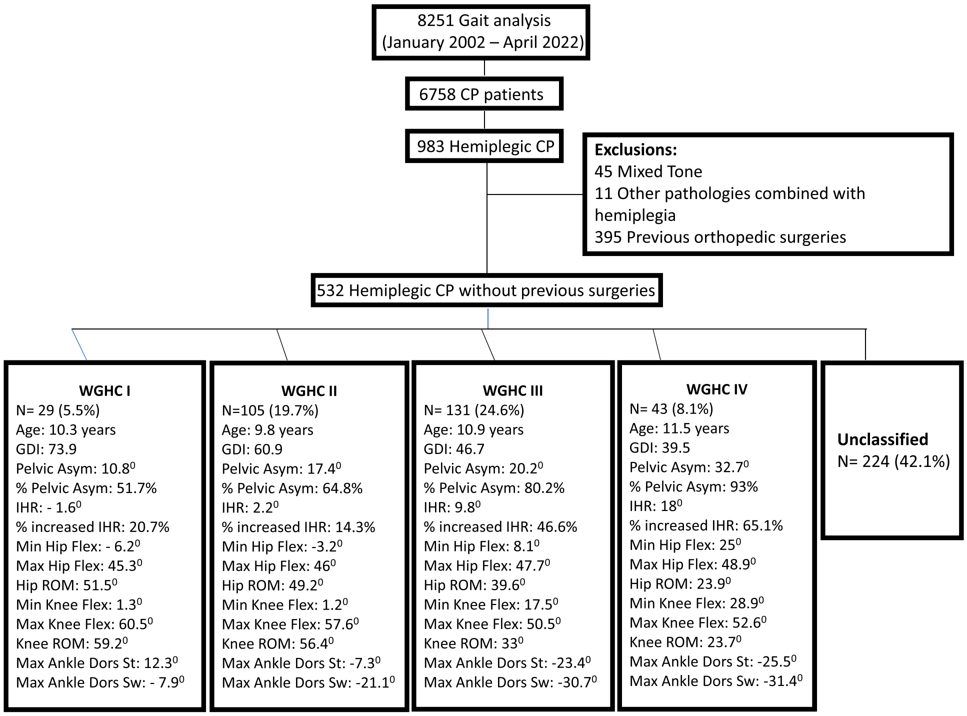

Fig. 1. Flowchart of subjects' selection and Winters et al. classification, including demographics, GDI and kinematics features. legend: CP (Cerebral Palsy), N (number of patients), GDI (Gait Deviation Index), Asym (Asymmetry), IHR (internal hip rotation), Min Hip Flex (minimum hip flexion), Max Hip Flex (maximum hip flexion), ROM (range of motion), Min Knee Flex (minimum knee flexion), Max Knee Flex (maximum knee flexion), Max Ankle Dors St (maximum ankle dorsiflexion in stance phase), Max Ankle Dors Sw (maximum ankle dorsiflexion in swing phase).

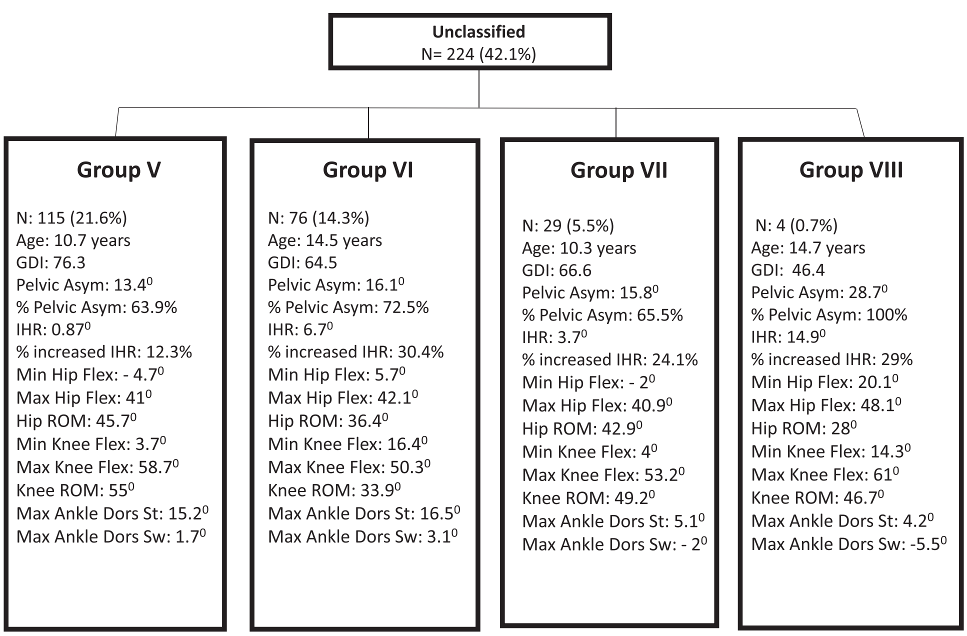

Fig. 2. Division of the unclassified subjects in four groups according kinematics characteristics. legend: CP (Cerebral Palsy), N (number of patients), GDI (Gait Deviation Index), Asym (Asymmetry), IHR (internal hip rotation), Min Hip Flex (minimum hip flexion), Max Hip Flex (maximum hip flexion), ROM (range of motion), Min Knee Flex (minimum knee flexion), Max Knee Flex (maximum knee flexion), Max Ankle Dors St (maximum ankle dorsiflexion in stance phase), Max Ankle Dors Sw (maximum ankle dorsiflexion in swing phase).

Perinatal anoxia (33.3 %) was reported more frequently in Group VII than in any other group. Patients from Group VII also showed a higher frequency of prematurity (42.2 %) than in Groups II (38.8 %, $p = 0.031$), III (35.6 %, $p = 0.003$), IV (38.6 %, $p = 0.031$), V (29 %, $p < 0.001$) and VI (29.6 %, $p < 0.001$) and of cardiorespiratory arrest (8.9 %) than in Groups II (0.9 %, $p = 0.002$), III (2.3 %, $p = 0.010$), V (1.6 %, $p = 0.005$) and VI (2.8 %, $p = 0.045$). The number of patients with post-natal central nervous system infection was greater in Group I (8.8 %) than in Groups II (0.9 %, $p = 0.014$) and III (1.5 %, $p = 0.027$). Congenital brain malformations were more frequent in Group IV (6.8 %) than in Groups III (0.7 %, $p = 0.015$) and V (0 %, $p = 0.003$). Seizures were seen more frequently ($p = 0.047$) in Group VI (9.8 %) than in

Table 1 –
Patient age and inter-group comparison.

Groups	Mean (years)	Median (years)	SD (years)	Min (years)	Max (years)	N	Inter-group comparison (*p*<0.05) II	III	IV	V	VI	VII
I	10.3	9.2	3.8	5.6	23.5	29	0.994	0.996	0.874	1.000	**<0.001**	1.000
II	9.8	9.1	3.5	4.0	22.5	105		0.376	0.185	0.600	**<0.001**	0.996
III	10.9	10.2	4.2	3.6	33.6	131			0.960	1.000	**<0.001**	0.993
IV	11.6	11.3	3.9	4.2	20.5	43				0.897	**0.004**	0.853
V	10.7	10.8	3.4	3.0	19.2	122					**<0.001**	0.999
VI	14.5	12.7	5.7	6.8	33.5	69						**<0.001**
VII	10.3	9.5	3.4	4.5	18.5	29						

Legend: SD (standard deviation), Min (minimum value), Max (maximum value), N (number of patients).

Table 2 –
Patients' GDI and inter-group comparison.

Groups	Mean	Median	SD	Min	Max	N	Inter-group comparison (*p*<0.05) II	III	IV	V	VI	VII
I	74.0	71.8	13.6	49.3	105.9	29	**<0.001**	**<0.001**	**<0.001**	0.979	**0.026**	0.417
II	61.0	62.3	13.6	26.0	83.8	104		**<0.001**	**<0.001**	**<0.001**	0.615	0.351
III	46.8	44.0	14.2	20.2	78.5	130			**0.035**	**<0.001**	**<0.001**	**<0.001**
IV	39.5	36.4	12.6	21.9	73.2	43				**<0.001**	**<0.001**	**<0.001**
V	76.3	77.1	12.1	41.7	103.3	122					**<0.001**	**0.013**
VI	64.5	66.9	13.9	28.8	94.1	69						0.985
VII	66.9	70.8	14.8	33.2	88.5	29						

Legend: GDI (Gait Deviation Index), SD (standard deviation), Min (minimum value), Max (maximum value), N (number of patients).

Table 3 –
Pelvic asymmetry in transverse plane and inter-group comparison.

Groups	Mean	Median	SD	Min	Max	N	Inter-group comparison (*p*<0.05) II	III	IV	V	VI	VII
I	10.8	8.9	8.0	0.3	27.6	29	0.121	**0.003**	**<0.001**	0.942	0.416	0.685
II	17.5	16.1	11.9	0.4	57.3	105		0.568	**<0.001**	0.160	0.993	0.996
III	20.3	19.0	12.7	0.2	54.1	131			**<0.001**	**<0.001**	0.254	0.569
IV	32.7	33.0	17.3	5.9	97.7	43				**<0.001**	**<0.001**	**<0.001**
V	13.4	11.4	10.1	0.5	51.2	122					0.746	0.959
VI	16.2	14.2	10.9	0.4	42.9	69						1.000
VII	15.9	15.5	13.4	1.0	58.7	29						

Legend: SD (standard deviation), Min (minimum value), Max (maximum value), N (number of patients).

Table 4 –
Internal hip rotation and inter-group comparison.

Groups	Mean	Median	SD	Min	Max	N	Inter-group comparison (*p*<0.05) II	III	IV	V	VI	VII
I	-1.6^{0}	-5.4^{0}	10.7^{0}	-18.8^{0}	22.7^{0}	29	0.686	**<0.001**	**<0.001**	0.940	**0.018**	0.556
II	2.2^{0}	1.9^{0}	9^{0}	-19.0^{0}	25^{0}	105		**<0.001**	**<0.001**	0.976	0.146	0.995
III	9.9^{0}	9.8^{0}	12.9^{0}	-24.2^{0}	41.8^{0}	131			**0.001**	**<0.001**	0.503	0.124
IV	18.0^{0}	17.3^{0}	14.5^{0}	-9.7^{0}	48.5^{0}	43				**<0.001**	**<0.001**	**<0.001**
V	0.9^{0}	0.2^{0}	9.5^{0}	-21.3^{0}	35.8^{0}	122					**0.013**	0.887
VI	6.7^{0}	7.3^{0}	12.5^{0}	-21.3^{0}	43.2^{0}	69						0.905
VII	3.7^{0}	3.1^{0}	12.5^{0}	-27.9^{0}	28.5^{0}	29						

Legend: SD (standard deviation), Min (minimum value), Max (maximum value), N (number of patients).

Group III (3 %) and intrauterine stroke had a higher frequency ($p = 0.015$) in Group IV (6.8 %) than in Group III (0.7 %). Finally, the number of patients with unidentified etiologic factors was higher in Group V (29 %) than in Groups II (18.1 %, $p = 0.041$), IV (9.1 %, $p = 0.006$) and VII (6.7 %, $p = 0.013$) and in Group VI (29.9 %) than in Groups IV (9.1 %, $p = 0.015$) and VII (6.7 %, $p = 0.026$). In Group VIII, 3 patients (75 %) had a history of perinatal anoxia while 1 subject (25 %) did not have any identified CP etiologic factors. No comparisons were carried on out in Group VIII due the small number of patients in this group (Supplementary materials 1 and 2).

4. Discussion

WGHC was unable to classify 224 (42.1 %) patients in the studied group and most of them (115/21.6 %) presented mild deviations, as observed previously by Riad et al., McDowell et al. and Tsitlakidis et al. [6–8]. However, Tsitlakidis et al. mentioned in 2019 that unclassified patients by WGHC were probably a heterogeneous group and there was a need for further characterization [8]. In the present study, we were able to characterize 4 different patterns of patients that did not fit into any WHGC group.

The most prevalent pattern of unclassified patients was seen into

Group V, and it was characterized by very mild patients, without any of the gait deviations described by WGHC. The pelvic asymmetry in the transverse plane and IHR in Group V was like that observed in Group I. They displayed a similar GDI to the WGHC Group I and higher than other Groups. Moreover, CP etiologic factors weren't identified in 29 % of them and this percentage is greater than observed in Groups II, IV and VII.

In Group VI, patients with reduced knee or hip range of motion were assembled, but with no restriction for ankle dorsiflexion in the stance and swing phases. Patients in this group, exhibited the alterations observed in WGHC III and IV, but with normal ankle dorsiflexion. The mean age in Group VI was higher than in other groups. Riad et al. [6] observed that patients might present increased impairment with greater age, however the present study did not achieve similar findings, and Group VI had the greatest mean age, but higher severity on gait pathology was detected in Group IV. The mean age in Group IV (11.6 years) was similar to other Groups and lower than Group VI (14.5 years). On the other hand, Group VI was characterized by a reduced hip and/or knee range of motion due to an increase in flexion during the stance phase, which might be observed later, after a growth spurt.

Group VII was composed by patients with deviations seen in WGHC II, III and IV, but with normal ankle dorsiflexion in swing phase. Perinatal anoxia was reported more frequently in Group VII than in the other Groups. In 2022, Tharaldsen et al. mentioned that even though the prevalence of post-natal CP has decreased in the last years, spastic hemiplegic CP was more frequent in this group than in the group that had pre-natal etiologies. The leading post-natal causal events observed by Tharaldsen et al. were cerebrovascular (32.8 %), head injuries/other accidents (22.4 %), infections (19.4 %) and hypoxic events (14.9 %) [13].

A reduction of ankle dorsiflexion in the stance and swing phases was observed, in addition to a reduction of hip range of motion, but with normal knee range of motion in 4 patients. We classified these subjects as Group VIII; however, no comparisons were carried out with other Groups due to the small number of patients in this group. Moreover, the gait pattern presented in Group VIII was very unusual and atypical.

The patterns observed in groups VI, VII and VIII in the present study didn't follow the severity of impairment at lower limbs from distal to proximal, as described previously by Winters et al. [2]. We believe that the large number of patients enrolled in the present study makes possible to identify these new patterns and it opens an opportunity for an update of WGHC addressing all subtypes. We suggest an inclusion of Group 0 in WGHC, and this group would be composed by patients with mild impairment and none of deviations described by Winters et al. (like Group V in the present study) [2]. Group II would have subtypes A and B. The subtype IIA would have the same features described in Group II in WGHC, while IIB would have no restriction for ankle dorsiflexion in swing phase (like Group VII in the present study). Groups III and IV would have subtypes A, B and C. The subtypes IIIA and IVA would be like Groups III and IV of WGHC, respectively. Peak ankle dorsiflexion will be inside normal reference values in swing phase in subtypes IIIB and IVB (like Group VII in the present study) and in stance plus swing phases in IIIC and IVC (like Group VI in the present study). Finally, a Group V would be included in the reviewed WGHC, and this group would be formed by patients with reduction of hip range of motion and ankle dorsiflexion, but with knee range of motion inside normal reference values (Supplementary material 3).

Regarding transverse plane, we noticed in this study a higher severity of gait pathology in Group IV, even after the identification of 4 new Groups. All new groups had transverse plane deviations milder than Group IV, which had a higher prevalence and PA mean values in the transverse plane, increased IHR, and the lowest GDI. Rodda and Graham had reported previously in 2001 the presence of increased IHR in type IV WGHC [3]. Similar findings were published by Aminian et al., when 71 patients with hemiplegic CP (mean age 8.4 years) were evaluated, and they mentioned that the average internal hip rotation was higher in type IV (18.4^0) than in types I and II, but similar in type III (9.8^0) [4]. The IHR mean in Groups III (9.9^0) and IV (18^0) in this study were very similar to values observed by Aminian and coauthors, however we were able to find a statistical difference between these two Groups due the larger number of analyzed patients.

However, it is important to mention the limitations of the present study. Firstly, this was a retrospective, uncontrolled cohort study with inherent difficulties associated with this methodology. The information on the CP etiology was collected from the medical records of the gait laboratory, but not all patients had it described in the files. Moreover, Group VIII was composed by just 4 patients and no comparisons were carried out with the other groups due to this small sample size.

On the other hand, the number of patients analyzed is the strength of this study, and due to this it was possible to identify gait patterns for hemiplegic CP which hadn't been described previously. Moreover, to mitigate the influence of previous gait surgeries, we only included patients who hadn't received any orthopedic surgical procedures on lower limbs. In 2007, Riad et al. mentioned that the small number of patients per group and lower mean age (8.1 years) in their study probably influenced the comparison with WGHC [6]. In the present study, the mean age of patients was very similar to Winters. et al. study (11.2 years) [2]. Moreover, Tsitlakidis et al. evaluated 89 patients with hemiplegia, and they mentioned that the unclassified ones formed a heterogeneous group and there was a need for further characterization [8]. In the present study, we were able to identify 4 additional gait patterns besides those described by WGHC and an update of this classification was suggested, however further investigation is needed to evaluate the reliability of it. The identification of the additional new groups amplifies the knowledge of gait pathology in hemiplegic cerebral palsy, providing more information for the treatment decision-making process. The WGHC is a helpful tool in the treatment decision-making process for types I, II, and III. In type IV, the prevalence of transverse plane deviations is higher, and WGHC is not sufficient for treatment planning. Moreover, the patterns observed in groups VI, VII, and VIII in the present study did not follow the severity of impairment in the lower limbs, from distal to proximal, as previously described by WGHC. Because of this, the treatment plan must be tailored for these new groups according to the deviations observed.

5. Conclusions

In the present study, 57.9 % of patients were classified according to WGHC and 4 additional patterns were identified, leading a proposal of update at WGHC.

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CRediT authorship contribution statement

Przysiada Laís: Data curation. **Fujino Marcelo H:** Writing – review & editing. **Kawmura Catia M:** Writing – review & editing, Validation, Data curation. **Morais Filho Mauro Cesar:** Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration, Methodology, Conceptualization. **Lopes José Augusto F:** Writing – review & editing, Data curation. **Antunes Silva Maria Eduarda:** Data curation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.gaitpost.2025.03.026.

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