Risk factors for hip dislocation in spastic cerebral palsy

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Abstract

Background and objectives: Hip dislocation is a prevalent occurrence among children afflicted with spastic cerebral palsy. It has the potential to induce impairment of function, and a decline in the quality of life. Early prevention and management of hip dislocation remains an intricate problem. Our objective is to elucidate the risk factors influencing hip dislocation in children with spastic cerebral palsy.

Methods: We included children with spastic cerebral palsy who were admitted to Dongzhimen Hospital, Beijing University of Chinese Medicine between January 2016 and January 2023. Participants' comprehensive clinical information, encompassing aspects such as gender, age, gestational age, birth weight, Gross Motor Function Classification System (GMFCS) level, and age of first standing, could be meticulously retrieved from medical records. All participants underwent pelvic X-ray examination. The severity of hip dislocation was assessed through the meticulous calculation of the Migration Percentage (MP) of the femoral head. Meanwhile, Acetabular Index (AI) and Neck-Shaft Angle (NSA) were obtained. Correlation analysis and multiple linear regression analysis were performed in the subsequent process.

Results: A total of 291 patients (206 males and 85 females) fulfilled the inclusion criteria and were subsequently included in the analytical scope. The mean age was 8.3 years, ranging from 2 to 16 years. Correlation analysis showed that gender, age, gestational age, and birth weight were not related to MP ($p > 0.05$). Multiple linear regression analysis revealed that GMFCS level ($p < 0.001$), AI ($p < 0.001$), NSA ($p < 0.001$), and age of first standing ($p < 0.001$) bore the stature of independent risk factors for MP.

Conclusions: Our finding has revealed that GMFCS level, AI, NSA, and age of first standing are independent risk factors for the progression of MP in spastic cerebral palsy children. This study provided a new insight for the anticipation of hip dislocation.

Introduction

Cerebral palsy (CP) is a non-progressive brain injury caused by premature birth, difficult delivery, asphyxia, and jaundice during the immature stages of brain development. It primarily manifests as abnormal posture and movement disorders [1]. In developed countries, the prevalence of CP is 2.0-3.5 per 1000 live births [2, 3]. Owing to economic and medical variables, developing countries encounter even more elevated incidence rates. Dominating the subtypes, spastic cerebral palsy (SCP) constitutes around 76–80% [4]. Its hallmark features include heightened muscle tone, muscle spasms, and joint contractures, often leading to the loss of the ability to walk normally. This necessitates lifelong care, placing significant economic burden on families and society, while also severely impacting the psychological well-being of affected individuals.

Hip dislocation ranks as the second most prevalent deformity in individuals with cerebral palsy, following equinovarus foot deformity [5]. Epidemiological studies indicate that approximately one-third of children with cerebral palsy encounter hip dislocation. The causes of hip dislocation are multifaceted. Primarily, individuals with SCP frequently present heightened tension in lower limb musculature, causing hip flexion

and persistent maintenance of maladaptive posture, potentially inducing femoral anteversion. Secondly, SCP children frequently lack adequate ambulatory capacity, resulting in considerably diminished standing and walking duration relative to their counterparts. This insufficient stress applied to the hip joint further contributes to deviant hip maturation [6]. Penner et al. [7] reported that hip dislocation is the most common cause of pain in children and young people with cerebral palsy. Jung et al. [8] found that as migration percentage (MP) increases, the quality of life of affected individuals gradually deteriorates. Hip dislocation poses a series of adverse effects on SCP children, emphasizing the critical importance of early diagnosis and intervention for hip dislocation.

Sweden [9], Norway [10], and Australia [11] have successively established hip joint monitoring program, which hold significant importance in early screening for hip dislocation and avoiding salvage surgeries in the future. However, due to China's large population and vast territory, a similar monitoring platform has not yet been established, and early diagnosis of hip dislocation remains challenging. Therefore, this study aims to clarify the risk factors for hip dislocation in SCP children in China by analyzing the correlation between variables and MP, so as to enhance early diagnostic capabilities and offer practical data support for developing tailored prevention and treatment strategies in the Chinese context.

Materials and methods

Study design

This study was a single-center, retrospective trial. The clinical trial protocol complied with the CONSORT clinical trial guidelines and was approved by the ethics committee of Dongzhimen hospital, Beijing University of Chinese Medicine (2023DZMEC-102-02) in May 2023. All participants signed a statement of informed consent before participating in the study.

Patients

We recruited patients with SCP who hospitalized Dongzhimen hospital, Beijing University of Chinese Medicine between January 2016 and January 2023. All patients were diagnosed as SCP (lower limbs) by a pediatric neurologist [12]. The inclusion criteria were as follows: Age ranging from 2 to 18 years; Devoid of any prior spinal or orthopedic interventions; Capable of acquiring high-quality anteroposterior pelvic radiographs; Amenable to obtaining dependable electronic medical records. Children with conditions beyond pure SCP and those presenting afflictions of the spine or pelvis, such as spinal tuberculosis, tethered spinal cord syndrome, and femoral head necrosis, have been excluded.

Methods

Migration Percentage (MP), Acetabular Index (AI), Neck-Shaft Angle (NSA) were measured using plain pelvis. The aforementioned measurements were all obtained from the most severely affected hip joint, referred to as the 'worst' hip. This evaluation was conducted by three proficient radiologists utilizing the imaging system (IMPAX Client) at the Dongzhimen Hospital, Beijing University of Chinese Medicine. The resultant data were averaged for accuracy. During the acquisition of pelvic radiographs at our facility,

patients were required to lie supine with the pelvis neither tilted nor rotated, maintaining a horizontal alignment with the ground, and the patella situated anteriorly. Utilizing cushioning materials, the hip and knee joints were flexed to compensate for lumbar lordosis. The range of hip joint adduction or abduction was limited to ≤ 6° [13].

We extracted Gender, age, gestational age, birth weight, Gross Motor Function Classification System (GMFCS) level, and age of first standing from the medical records. The assessment of GMFCS was undertaken by a seasoned pediatrician, adhering to the Gross Motor Function Classification System, which graded across five levels ranging from I to V, is age-dependent [14].

We designated MP as the dependent variable, while Gender, age, gestational age, birth weight, GMFCS level, age of first standing, AI, and NSA were designated as independent variables. Employing correlation analysis, we sought to explore independent variables that exhibit a notable correlation with MP. From the screened independent variables, a regression equation was constructed using multivariate linear regression analysis. The progression of the study is visually represented in Fig. 1.

Statistical analyses

Data were subjected to statistical analysis using SPSS 26.0 software. Quantitative data were presented as mean ± standard deviation (x ± s). The correlation between parameters was assessed through Spearman's correlation coefficient (r). Multivariate linear regression analysis was conducted to uncover the impact of variables on MP. A p-value of less than 0.05 was deemed to hold statistical significance.

Results

366 children with SCP were obtained, 75 children were excluded for lack of necessary clinical data and/or X-ray of pelvis. A total of 291 children (male:206; female:85) fulfilled the inclusion criteria and were included in the analyses. Demographic characteristics of the participants were summarized in Table 1. The average age was 8.3 years (range from 2 to 16 years). 57 patients were classified as GMFCS level I (19.59%), 92 GMFCS level II (31.62%), 82 GMFCS level III (28.19%), 60 GMFCS level IV (20.6%). The mean gestational age was 33.24 weeks (range from 24 to 42 weeks). The mean birth weight was 2.42 kg (range from 0.88 to 5.4 kg). The mean age of first standing was 22.09 months (range from 9 to 38 months). The average MP was 31.67% (range from 9 to 100%). The average AI was 24.35° (range from 5.8 to 56°). The average NSA was 155.76° (range from 130.1 to 179.2°). The visualization of correlation analysis between variables and MP is shown in Fig. 2.

Table 1
Clinical information of patients with spastic cerebral palsy (n = 291)

Sex, n (%)	
Male	206 (70.79)
Female	85 (29.21)
Mean age, y (range)	8.3 (2−16)
GMFCS level, n (%)	
I	57 (19.59)
II	92 (31.62)
III	82 (28.19)
IV	60 (20.6)
Mean gestational age w (range)	33.24 (24−42)
Mean birth weight kg (range)	2.42 (0.88−5.4)
Mean age of first standing m (range)	22.09 (9−38)
MP % (range)	31.67 (9-100)
AI ° (range)	24.35 (5.8−56)
NSA ° (range)	155.76 (130.1-179.2)

Correlation analysis revealed that gender (r = 0.025, p = 0.666), age (r = -0.163, p = 0.005), gestational age (r = 0.020, p = 0.737), and birth weight (r = -0.025, p = 0.670) were not related to MP. GMFCS level (r = 0.513, p = 0.000), AI (r = 0.632, p = 0.000), NSA (r = 0.658, p = 0.000), and age of first standing (r = 0.702, p = 0.000) were significantly related to MP (Table 2). To elucidate whether GMFCS level, AI, NSA, and age of first standing were independent risk factors for MP, we performed multiple linear regression analysis. The result showed that GMFCS level (t = 4.795, p = 0.000), AI (t = 4.290, p = 0.000), NSA (t = 6.651, p = 0.000), and age of first standing (t = 6.298, p = 0.000) were independent risk factors for MP (Table 3). We constructed the regression equation between MP and 4 variables:

$$MP = -37.769 + 2.621 \times GMFCS + 0.32 \times AI + 0.290 \times NSA$$
$$+ 0.461 \times Age\ of\ first\ standing$$
$$(R^2 = 0.565,\ F=92.928,\ p = 0.000,\ DW = 1.984)$$

Table 2
Correlation Analysis between MP and Variables (n = 291)

MP (%)	r	P
Gender (1 = male, 2 = Female)	0.025	0.666
Age	-0.163	0.005
Gestational age	0.020	0.737
Birth weight	-0.025	0.670
GMFCS level	0.513	0.000
AI	0.632	0.000
NSA	0.658	0.000
Age of first standing	0.702	0.000

Table 3
Regression Coefficients and Standard Errors for a Multiple Linear Regression of Odds Ratio for MP on Different Explanatory Variables (n = 291)

Covariate	Estimated Regression Coefficient	Estimated Standard Error	Test Statistic (T)	Significance Level (p Value)
GMFCS level	2.621	0.547	4.795	0.000
AI	0.320	0.075	4.290	0.000
NSA	0.290	0.044	6.651	0.000
Age of first standing	0.461	0.073	6.298	0.000

Discussion

Hip dislocation is a prevalent and severe issue in CP. The primary methods for diagnosing hip dislocation include X-rays and CT scans, with X-rays being the most accessible and widely utilized. In 1980, Reimers introduced the concept of the MP to objectively assess the relationship between the femoral head and the acetabulum [15]. According to MP values, hip joints are categorized as normal (< 30%), subluxated (30–89%), or dislocated (> 90%) [10]. Scholars advocate for a graded treatment approach for hip dislocation in CP, encompassing preventive, reconstructive, and salvage surgeries [16]. MP serves as a reliable and sensitive marker, serving as the gold standard for diagnosing hip dislocation and is extensively employed in most hip joint monitoring programs [17, 18]. Thus, in this study, MP was selected as the dependent

variable to establish its relationship with multiple variables, elucidating the risk factors influencing MP progression and providing a basis for early prediction of hip dislocation.

Previous research suggested that hip dislocation may manifest at an early age. A 20-year follow-up study on hip joint monitoring revealed that some children exhibited hip subluxation at the ages of 2 [19]. Terje et al. [10] discovered that among a cohort of patients, complete hip dislocation occurred at a mean age of 4 years and 5 months, and upon final follow-up, the MP increased from an initial 20.4–34.0%. Another study with an average follow-up of 11 years found that 25% of hip joints progressed from an initial 30% MP to 60%, and 10% eventually developed complete hip dislocation [20], which suggested that MP progression is age-related. However, the results of our study indicate no significant correlation between MP and age, possibly due to the majority of children being under 10 years old (171 individuals), leading to an uneven age distribution within the sample. Concurrently, this study found no significant correlation between MP and gender among children with SCP. Numerous follow-up studies have pointed out that there is no significant difference in hip dislocation occurrence rates between different genders of CP patients [17, 18, 19], aligning with our conclusion.

Prematurity and low birth weight are principal etiological factors of CP [21], not only elevating the incidence of CP among live births but also contributing to higher mortality rates among CP children [22]. Our study demonstrated an average gestational age of 33.24 weeks and an average birth weight of 2.42 kg, corroborating this conclusion. However, exploration of the relationship between hip joint development in CP children and gestational age and birth weight remains limited. Kyoko et al. [23] included 81 cases of dyskinetic CP children and analyzed the correlation between MP and gestational age, as well as birth weight, finding that neither gestational age nor birth weight independently contributed to hip dislocation in dyskinetic CP children. To the best of our knowledge, we are the first to investigate the association between gestational age, birth weight, and hip dislocation in SCP children, and our results also fail to establish a significant correlation between these variables and hip dislocation.

The GMFCS, serving as an objective measure of gross motor function in CP patients, has found wide application. A higher GMFCS level indicates poorer motor function. Multiple studies have demonstrated a direct relationship between GMFCS grading and hip dislocation [24, 25]. Observations on the rate of MP progression among different GMFCS levels revealed that MP increased by 0.2% per year in GMFCS level I children, while it surged by 9.5% annually in level V children [10]. Our study revealed that GMFCS grading stands as an independent risk factor for MP increase. Worth noting is that our research focused on a specific subtype of CP, namely SCP, enhancing the level of evidence of our findings. Additionally, we acquired data regarding the age at which the children stood independently for the first time. Given the peculiar nature of cerebral palsy, parents are particularly attuned to the timing of changes in walking ability during their child's growth. An earlier age of independent standing implies greater motor potential in children. Our results uncovered that the age of independent standing is an independent risk factor for MP increase, showing a positive correlation with MP increase. In children with SCP, damage to upper motor neurons frequently results in heightened muscle tone. Among the primary muscle groups surrounding the hip joint, the iliopsoas, adductors, and hip abductors are affected by persistent spasticity

of the adductors, leading to sustained adduction of the femur and hampering the development of hip abductors, ultimately diminishing their strength. The imbalance between muscle strength and tone induces further adduction of the hip joint, pulling the femoral head outward, exacerbating hip dislocation [26]. Compared to typically developing children, those with higher GMFCS levels exhibit shorter walking times and distances, significantly reducing stress on the acetabulum, which consequently impacts the development of the hip muscles and ligaments. Hence, we contend that the coexistence of spasticity and reduced motor capacity accelerates the occurrence of hip dislocation.

AI is the angle formed by the line connecting the lowermost point of the inner margin of the bilateral acetabula (H-line) and the line connecting the uppermost point of the outer margin of the acetabulum and the lowermost point of the inner margin. AI effectively reflects acetabular development and stands as a key indicator for assessing acetabular dysplasia, with an elevated AI being correlated with poor acetabular development [27]. Wang et al. [28] established a relationship between AI and MP in cerebral palsy children and found a positive correlation, indicating that worse acetabular development corresponds to more severe hip dislocation. Our study discovered that AI is an independent risk factor for MP increase. This further confirms that inadequate acetabular development accelerates the occurrence of hip dislocation. Importantly, those conducting imaging measurements should be aware that increased acetabular anteversion and incomplete posterior acetabular coverage are common in cerebral palsy, which could affect the accuracy of AI measurement [29].

NSA was calculated by measuring the angle between a line passing through the center of the femoral shaft and a line connecting the centers of the femoral head and the midpoint of the femoral neck. NSA can reflect femoral proximal anteversion. Hip external rotation is a common deformity of the hip joint secondary to lower limb spasticity. It is characterized by an increased angle between the femoral head and the femoral shaft, resulting in a more upright position of the femoral head and neck. Therefore, when NSA increases, the severity of hip external rotation deformity tends to worsen [30]. Finlayson et al. [31] found a correlation between hip external rotation and hip dislocation in children with GMFCS IV-V level cerebral palsy, though the study did not specifically focus on CP subtypes. Our study confirmed this relationship in SCP. MP represents femoral displacement, AI reflects acetabular development, and NSA reveals femoral head rotation. These three factors are closely interrelated. In future research, attention should be directed toward these three aspects to achieve precise prediction of hip dislocation in cerebral palsy.

However, there are limitations to this study. Selective dorsal rhizotomy (SDR) is one of the main surgical treatments for CP at our center. Consequently, patients seeking treatment often have indications for SDR surgery. The criteria for this surgery require patients to possess a certain level of walking ability and to be capable of actively engaging in rehabilitation postoperatively. GMFCS level V patients generally have poor motor abilities and lack walking capacity. As a result, this study exclusively included patients classified as GMFCS levels I-IV, potentially introducing a selection bias.

Conclusions

Our findings have unveiled that GMFCS level, AI, NSA, and age of first standing are independent risk factors for the elevation of MP in SCP children. This novel insight provides an enhanced perspective for the anticipation of hip dislocation. Clinically, SCP patients harboring one or more risk factors confront escalated chances of hip dislocation incidence and progression, warranting early hip joint monitoring and subsequent follow-up for this subgroup. Moreover, an extensive longitudinal tracking study encompassing substantial sample sizes is requisite to ascertain the extent of dislocation progression over time under diverse risk factor circumstances, as well as to explore the preventive and therapeutic effects of varied early interventions. Furthermore, larger-scale clinical research, encompassing comprehensive cerebral palsy population registration at provincial and municipal levels, along with the construction of cerebral palsy hip dislocation predictive models through artificial intelligence, remain as prospects to be further explored in the future.

Declarations

Informed consent

Informed consent was obtained from all participants or, if participants are under 16, from a parent and/or legal guardian.

Authors' contributions

Gang Liu, and Huizhong Bai conceived and designed the study. Gang Liu wrote the original draft. Bowen Deng, Ruiqin Yu, Yong Jiao, Chuanyu Hu, Jingpei Ren, and Yi Zhao collected the data and analyzed. Lin Xu and Xiaohong Mu reviewed the manuscript.

Availability of data and materials

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request (muxiaohong2006@126.com).

Ethics approval and consent to participate

This study approved by the Ethics Committee of Dongzhimen Hospital, Beijing University of Chinese Medicine (2023DZMEC-102-02) in May 2023. All patients signed informed consent forms. All methods were performed in accordance with the relevant guidelines and regulations.

Consent for publication

The individual images and evaluation data involved in the paper were published with the informed consent of the individuals.

Competing interests

All authors declare that they have no potential conflct of interest.

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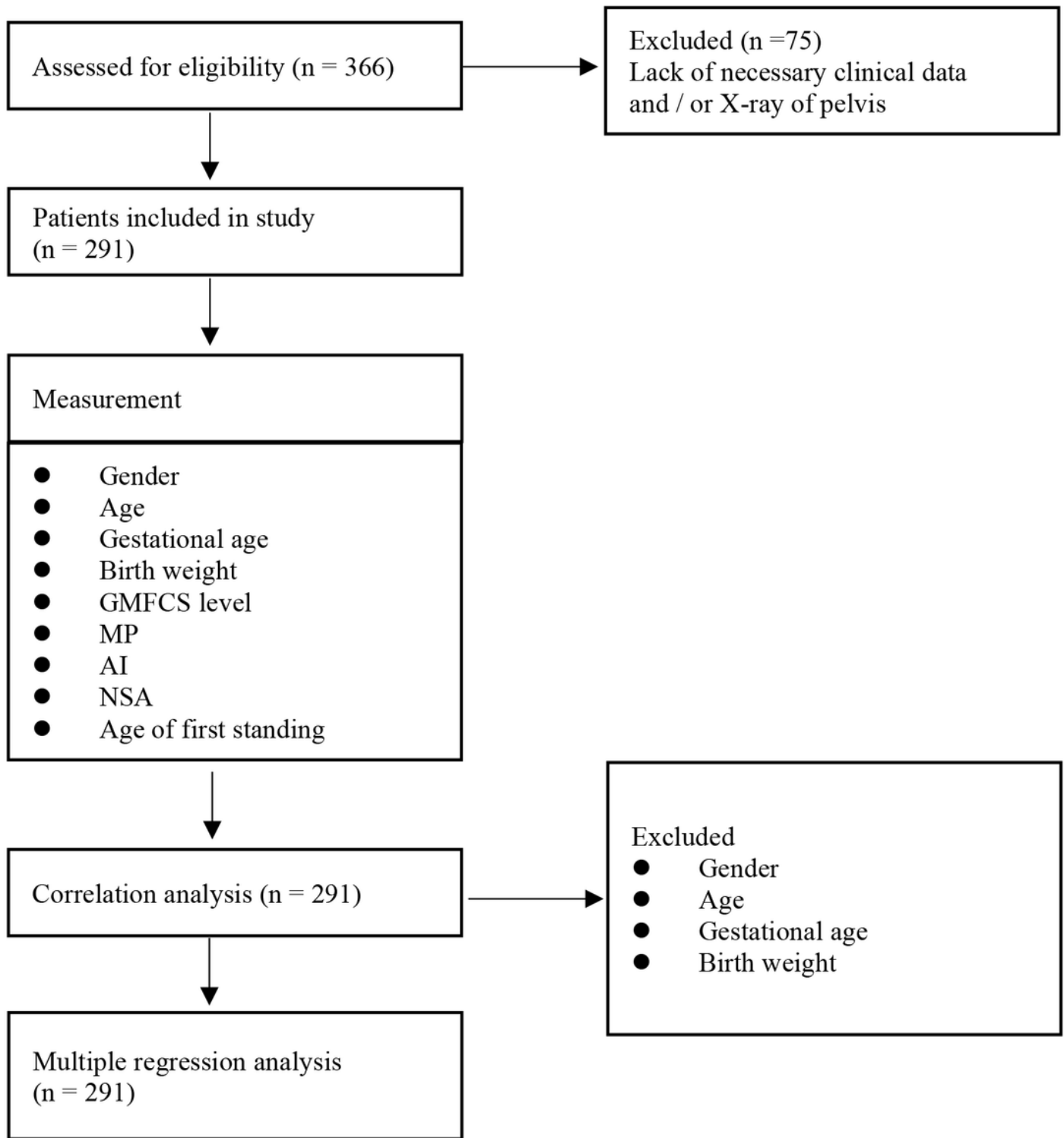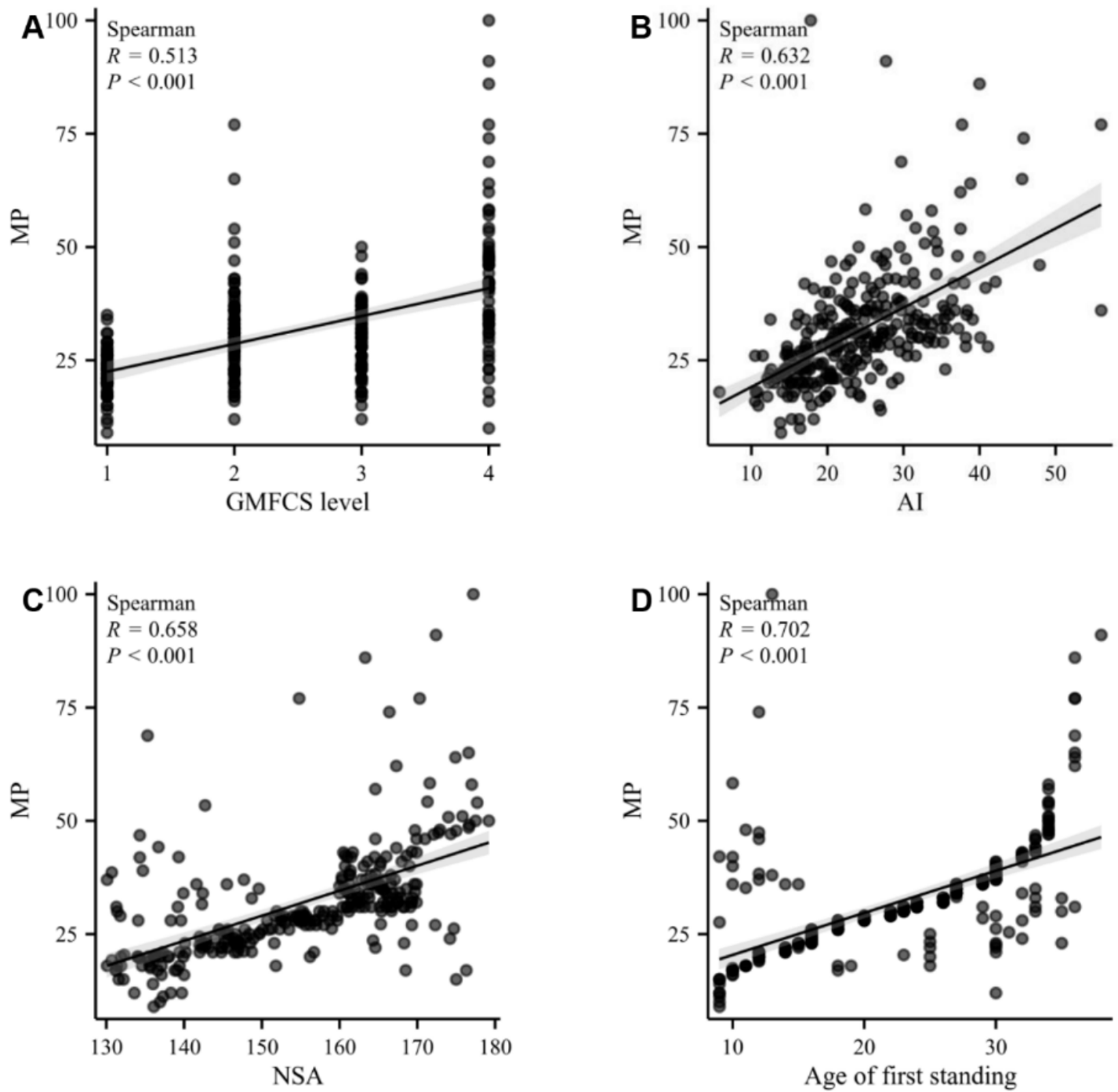
Figures

Figure 1

Study flowchart

Figure 2

Correlation Analysis between MP and Variables. **A** GMFCS level. **B** AI. **C** MP. **D** Age of first standing.