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A Diagnostic Clinical Prediction Rule for Predicting Hip Subluxation/ Dislocation in Patients with Cerebral Palsy

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ABSTRACT

OBJECTIVE Hip subluxation/dislocation, a common problem in patients with cerebral palsy (CP), needs to be diagnosed with hip radiography. However, patients with cerebral palsy in a rural or country border areas may not have access to a radiographic screening program due to transportation difficulties and cost. This study aims to develop a clinical prediction rule (CPR) for diagnostic prediction of hip subluxation/dislocation in patients with CP for use as a risk-screening tool.

METHODS This is a cross-sectional diagnostic CPR development study. Data were obtained from medical and radiologic records of patients with CP who had undergone outpatient follow-up at a 750-bed general hospital between January 2017 and December 2023. Clinical predictive factors were medical records plus hip subluxation/dislocation diagnoses using the migration percentage (MP), with ≥ 33% indicating hip subluxation and ≥ 90% indicating hip dislocation. Multivariable logistic regression analysis was used for choosing predictive variables and rating their coefficient. Both discriminative and calibration aspects of the performance of the CPR were evaluated using both a development and an internal validity model.

RESULTS Among the 69 patients with CP in the study, the mean (SD) age was 113 (242) months. Of the 69 patients, 30 were diagnosed with hip subluxation/dislocation, a prevalence of 43%. Using multivariable logistic regression analysis, a simple CPR performance calibration system was developed which included three factors: age ≥ three years (1 point), female sex (1 point), non-ambulatory status (Gross Motor Function Classification System (GMFCS) levels IV and V) (2 points). The discriminative ability of the CPR, evaluated using the area under the receiver operating characteristic curve (AuROC), was 0.776 (95%CI: 0.668-0.884) and the calibration curve showed acceptable performance in both the development and the internal validation models.

CONCLUSIONS Our diagnostic CPR for predicting hip subluxation/dislocation in patients with CP provides acceptable discriminative and calibration performance. This CPR may be used to evaluate the risk of hip subluxation/dislocation in settings where hip radiography is not available. Further external validation studies are needed to confirm the robustness of the performance before applying this CPR in other clinical settings.

KEYWORDS cerebral palsy, hip subluxation, hip dislocation, clinical prediction rule

INTRODUCTION

Hip subluxation/dislocation is an important complication in patients with cerebral palsy (CP). The prevalence of hip subluxation/dislocation is reported to be 25-60%, depending on the country of origin, the individual's characteristics, and the specific hip surveillance program used with the cohort (1-3). For Thailand, the prevalence of hip subluxation/dislocation reported by the Queen Sirikit National Institute of Child Health is 57% (4). It should be noted that this prevalence may be different from that of other health facilities in Thailand where no formal hip surveillance program has been implemented.

Hip subluxation/dislocation can be diagnosed using the Reimers migration percentage (MP). The MP is calculated from the distance between the lateral border of the femoral head and Perkin's line (A) divided by the distance between the medial and lateral borders of the femoral head as presented in a plain radiograph of the hip then converting the value to a percentage (5, 6) (Figure 1). Hip subluxation will be diagnosed if the MP is > 33% but < 90%, whereas hip dislocation will be diagnosed if the MP is ≥ 90%. Patients who have MP > 33% should be referred to an orthopedist for proper management, including close observation, preventive programs such as botulinum toxin injection, physiotherapy and surgical intervention (6, 7). Previous studies have demonstrated that several factors can prognose an event of hip subluxation/dislocation, including age (2), female sex (8), Gross Motor Function Classification System (GMFCS) level (2), bilateral spastic hemiplegic type of CP (9), initial MP (10, 11), and initial head-shaft angle from hip radiography (11).

Although hip radiography is the best tool for detecting hip subluxation/dislocation, not all patients with CP can access a radiography facility, especially those who live in rural or border areas of middle- or low-income countries which have very limited health care system resources as well as limited public transportation (12). These patients may only be able to access health services at community-level clinics in mountainous areas or temporary clinics at country borders which have no radiographic facilities. Transportation of patients with CP from these areas can be expensive and difficult. For that reason, it is important to be able predict whether these patients have a risk of hip subluxation/dislocation or not before sending them to a hospital which can confirm a diagnosis of hip subluxation/dislocation using hip radiography.

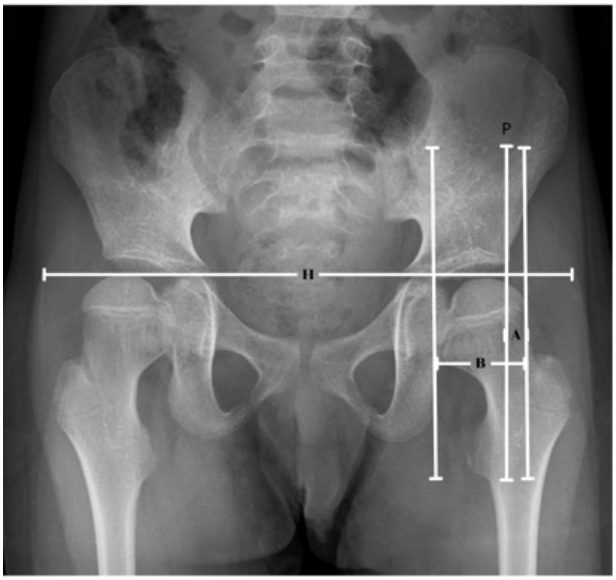

Figure 1. Migration percentage measurement

Determining predictive risk is to create a clinical prediction rule (CPR) which does not involve hip radiography (13). Instead of clinicians in areas lacking access to radiography having to depend on a single predictive factor or to have to deal with a difficult equation, CPR uses a set of predictive factors to determine the probability of the outcome by using a simple, ready-to-use scoring method (13). The CPR most frequently used in clinical settings is the APGAR score which is designed to predict the risk of birth asphyxia in newborns. However, to the best of our knowledge, there have been no studies about developing CPR for diagnostic prediction of hip subluxation/dislocation in patients with CP. The aims of this study are: 1) to report the prevalence of hip subluxation/dislocation in a general hospital which has no formal hip surveillance program, and 2) to develop a clinical prediction model for diagnosing hip subluxation/dislocation in patients with CP using data available at a general hospital that has no formal hip surveillance program.

METHODS

This is single-center, retrospective cohort study was conducted in an outpatient rehabilitation setting at a 750-bed general hospital. Data were obtained by reviewing electronic and written medical records of children with CP who had undergone outpatient follow-up at the

hospital between January 2017 and December 2023. Clinical and radiographic data of all participants were obtained on the day of the follow-up.

Participants

The inclusion criteria for this study were: 1) having been diagnosed with spastic CP and 2) age between 0-15 years. The exclusion criteria were: 1) incomplete medical data of hip subluxation status at the time of the first follow-up; and 2) being diagnosed with postnatal CP since patients with postnatal CP follow different courses and have different prognoses from those with congenital CP (5). Therefore, we decided to exclude patients with postnatal CP to increase the internal consistency of the study population.

Predictive variables

Pre-specified independent variables of hip subluxation were obtained from participants' medical records, including: 1) age at the onset of CP (months), 2) age at the time of assessment (months), 3) sex (male/female), 4) anatomical subtype of CP (quadriplegia/diplegia/hemiplegia), and GMFCS level (ranging from 1 [walking without limitation] to 5 [limitation in head and trunk antigravity control]) (2).

Outcome variable

The outcome variable was the hip subluxation status evaluated by hip radiography. Radiographic imagings of all participants were extracted from the picture archiving and communication system (PACS). Radiographic imagings were investigated on the affected side for participants with hemiplegia and both sides for participants with diplegia and quadriplegia. All hip radiography investigation was done with the patient in a supine position with parallel leg position and patella facing upward. The percentage of hip joint migration was recorded. Hip radiographic results were categorized into three groups based on the percentage of hip joint migration: normal (MP 0-32%), subluxation (MP 33-89%), and dislocation (MP ≥ 90 %) (5). The measurement method of MP is demonstrated in Figure 1. The MP value was obtained from medical records. If the MP value was not available in medical records, it was interpreted by a rehabilitation physician or orthopedic specialist with at least 10-years' experience in caring for patients with CP. Despite being a predictor of hip displacement in children with CP (10, 11), the head-shaft angle was not used in this study or in this hospital due to the complexity of the measurement, the variability in its interpretation, and the availability of simpler, standardized alternative measures such as the MP, which is commonly used in medical practice (9, 11).

Statistical analysis

All parameters were described using mean (SD), median (25^{th} percentile, 50^{th} percentile), and frequency (percentage), according to their type and distribution. A probability of less than 5% ($p < 0.05$) was considered statistically significant. All statistical analyses were conducted using STATA version 16 (StataCorp, College Station, Texas, USA). Complete case analysis was used in cases of missing data. No imputation was performed.

Prevalence of hip subluxation/dislocation

The prevalence of hip subluxation/dislocation was calculated as the ratio of the number of participants diagnosed with hip subluxation/dislocation to the number of all participants and is presented as a percentage (1-3).

Development of a prediction model

As this study used a predictive modelling strategy, parameter selection methods were applied to make the final model as parsimonious as possible, i.e., containing a minimal number of predictive parameters. First, data were analyzed using univariable analysis (Fisher's exact test for categorical parameters and the independent t-test for continuous variables) to eliminate all parameters that had $p > 0.2$. After that, univariable and multivariable logistic regression analysis of all remaining parameters was performed to obtain the odds ratio of all parameters. An area under the receiver operating characteristic curve (AuROC) of the regression model was then calculated. The regression model was reduced by removing the least significant factors, then the AuROC was calculated again. The AuROC of the initial model (containing all predictors) and the parsimonious model (containing only statistically significant factors) was compared using the chi-square test. If the AuROC was not significantly different, the model which included less predictive factors

were selected as a final model. After that, the regression coefficient of each predictive factor was divided by the smallest one and the results were rounded as an integer to simplify the coefficient. Then, a score from the developed CPR was calculated for all participants.

Evaluation of prediction model performance

The measurement discrimination and calibration were used as a demonstration of clinical prediction score performance (14). To evaluate the model's ability to differentiate between groups (hip subluxation/dislocation and non-hip subluxation/dislocation) was done using the AuROC. The measurement of calibration demonstrated the compatibility between the observed outcomes, represented by a locally weighted scatterplot smoothing (LOWESS) plot, and a predicted probability plot. The LOWESS plot is a regression analysis used to transform raw data into a smooth plot (15). It is an acceptable strategy for evaluating the calibration performance of the CPR (14). A cut-off level for the score was set by applying the diagnostic accuracy test as the level that produced the highest sensitivity and specificity when compared with the true diagnosis of the hip subluxation/dislocation.

Internal validation

According to the Transparent Reporting of a Multivariable Prediction Model for Individual Prognosis or Diagnosis (TRIPOD) guideline, evaluating internal validation is a requirement for developing CPR. Internal validation was performed using a bootstrapping approach (200 iterations), optimism-corrected C-statistics were used to evaluate model discrimination, and the expected-to-observed ratio was used to assess the model calibration (14).

Sample size calculation

Sample size calculation for the development of prediction model followed the method proposed by Riley, et al. (16). A sample size that had 10 outcome events per predictive factor was used. To keep our CPR from becoming too complicated, we included 3 potential predictive factors and at least 30 outcome events were required.

RESULTS

Characteristics of the participants

During 2018-2023, 131 patients with CP were identified from medical records. Of these patients, fourteen who had incomplete medical data and three who were diagnosed with postnatal CP were excluded from the analysis. Among the 117 initially included patients, 69 had undergone at least one hip radiographic screening, a prevalence of 59%. The data of those 69 patients were included in this study. The mean (SD) age at the time of screening was 113 (242) months (9.5 years) and the median (25^{th}, 75^{th} percentile) were 65 (37, 110). Seventeen patients (25%) were three years old or older at the time of screening. Forty-one patients (59%) were male. Nine patients (13%) were diagnosed as hemiplegic, 28 patients (41%) were diagnosed as diplegic, and 32 patients (46%) were diagnosed as quadriplegic CP. Two (3%), ten (14%), fifteen (22%), eighteen (26%), and twenty-four (35%) patients were categorized as grade 1, 2, 3, 4, and 5, respectively. Forty-two patients (61%) were diagnosed as non-ambulatory, as indicated by a GMFCS grade of 4 or 5. Forty-seven (67%) patients used a universal coverage health insurance scheme, while sixteen patients (23%) and six (9%) patients used cash payment and a health insurance scheme for foreigners, respectively.

Among the 69 patients, 30 were diagnosed with hip dislocation/subluxation, a prevalence of 43%. At the joint level, a total of 129 hip joints were assessed (bilateral for those with diplegia/quadriplegia, unilateral for those with hemiplegia). It was found that 36 joints (28%) had a hip problem. Among the patients with hip subluxation/dislocation (36 hips in 30 patients), it was noted that eight patients had hip dislocation (MP > 90). After orthopedic consultation, all the patients received surgery. Nine patients had MP between 50% and 99%. After orthopedic consultation, four underwent surgery while the remaining five were scheduled for intensive follow-up and received conservative prevention. The remaining patients had MP between 33% to 49% and received conservative prevention after orthopedic consultation (Figure 2).

Compared with the normal hip group, the subluxation/dislocation hip group had significantly more female patients (57% vs 28%, $p = 0.026$; Fisher

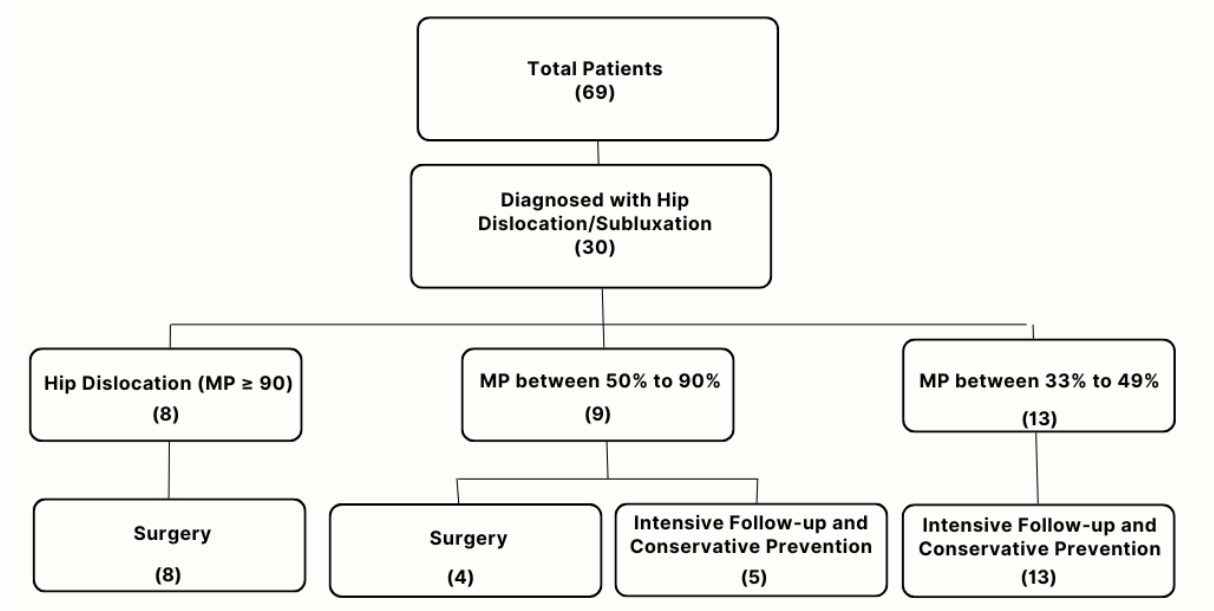

Figure 2. Flow chart of the study and referral/management pathway
MP, migration percentage

Table 1. Characteristics of the participants, categorized by hip subluxation/dislocation status

Parameters	Overall n=69	Hip subluxation/ dislocation n=30	Normal hip n=39	Crude odds ratio (95% CI)#	*p*-value
Age at screening, months					
Mean (SD)	113 (242)	121 (261)	107 (230)	1.00 (0.99-1.01)	0.819
Median (25th, 75th percentile)	65 (37, 110)	69.5 (42, 96)	64 (33, 113)		0.738
Age more than or equal to 3 years, n (%)	17 (25)	12 (31)	5 (17)	1.33 (0.69-7.21)	0.183
Sex, female, n (%)	28 (41)	17 (57)	11 (28)	3.33 (1.22-9.08)	0.026*
Type of CP, n (%)					0.216
Hemiplegic	28 (41)	11 (37)	17 (44)	Reference	
Diplegic	9 (13)	2 (7)	7 (18)	2.26 (0.40-12.97)	
Quadriplegic	32 (46)	17 (56)	15 (38)	3.96 (0.71-22.11)	
GMFCS, n (%)					0.206
Level 1	2 (3)	0 (0)	2 (5)	NA	
Level 2	10 (14)	3 (10)	7 (18)	Reference	
Level 3	15 (22)	4 (13)	11 (28)	0.89 (0.14-4.99)	
Level 4	18 (26)	10 (33)	8 (21)	2.92 (0.57-15.05)	
Level 5	24 (35)	13 (44)	11 (28)	2.76 (0.57-13.29)	
Non-ambulating status (GMFCS 4 and 5), n (%)	42 (61)	23 (77)	19 (49)	3.46 (1.21-9.92)	0.025*
Health insurance scheme					0.471
UC	47 (67)	23 (77)	24 (62)	References	
UC for foreigners	16 (23)	5 (17)	11 (28)	0.52 (0.09-3.13)	
Cash payment	6 (9)	2 (6)	4 (10)	0.47 (0.14-1.58)	

SD, standard deviation; CP, cerebral palsy; GMFCS, Gross Motor Function Classification System; UC, Universal Coverage, NA, not applicable
*significant level at $p < 0.05$ by independent t-test for mean (SD), Mann-Whitney U test for median (25th, 75th percentile), and Fisher exact test for n (%); #Crude odds ratio was calculated from univariable logistic regression analysis

exact test) and significantly more non-ambulatory patients (77% vs 49%, $p = 0.025$; Fisher exact test). No significant difference in age, type of CP, or health insurance scheme between the normal and the subluxation/dislocation hip group was found (all $p > 0.05$). Characteristics of this cohort are summarized in Table 1.

Development of CPR

Table 2 demonstrates the results of multivariable logistic regression analyses for diagnostic prediction of hip dislocation/subluxation. The

initial model consists of all predictors, including age ≥ 3 years, female sex, non-ambulatory status, type of CP, and health insurance scheme. The AuROC of the initial model was 0.808 (95%CI: 0.704-0.912). The parsimonious model consisted of only the three statistically significant predictors: age ≥ 3 years, female sex, and non-ambulatory status. The AuROC of the parsimonious model was 0.792 (95%CI: 0.684-0.899). Therefore, the parsimonious model was selected as a final model.

A simple CPR was created by dividing the regression coefficient of each factor (8.191 for non-ambulatory status and 5.420 for age ≥ 3 years) by the smallest one (4.549 for female sex) and rounding up, causing a multiplier of one for age ≥ 3 years and female sex and two for non-ambulatory status. A score of the developed CPR was calculated for all patients, resulting in a mean (SD) of 2.20 (1.01). The average score of patients with hip subluxation/dislocation was significantly higher than that of patients with a normal hip (2.93 vs 1.95; $p < 0.001$, independent t-test). The simple CPR is presented in Table 3.

Performance of the developed CPR

Discriminative ability of the developed CPR was evaluated using AuROC of the CPR (Figure 3). The developed CPR had an AuROC of 0.776 (95%CI: 0.668-0.884), indicating an acceptable discriminative ability (10). Calibrating ability of the developed CPR was evaluated using a calibration plot (Figure 4). The calibration plot demonstrates that the predicted probability of developing CPR and the observed probability are the same, i.e., the CPR underestimates the true risk of hip subluxation/dislocation at a score of 0-3 but overestimates the true risk of hip subluxation/dislocation at a score of 4.

Using a cut-off level of scores ≥ 3, the developed CPR has a sensitivity of 73.3% (95%CI: 54.1%-87.7%), a specificity of 76.9% (95%CI: 60.7%-88.9%), a positive predictive value (PPV) of 71.0% (95%CI: 52.0%-85.8%), a negative predictive value (NPV) of 78.9% (95%CI: 62.7%-90.4%), and a positive likelihood ratio (LR) of 3.18 (95%CI: 1.72-5.86). A cut-off level of scores ≥2 has a sensitivity of 93.3% (95%CI: 77.9%-99.2%), a specificity of 35.9% (95%CI: 21.2%-52.8%), a PPV of 52.8% (95%CI:

Table 2. Predictive factors of hip subluxation/dislocation in the initial and final model

Predictive variables	Initial model (AuROC = 0.808 [95%CI: 0.704-0.912])				Final model (AuROC = 0.792 [95%CI: 0.684-0.899])			
	Odds ratio	95%CI of B		p-value	Odds ratio	95%CI of B		p-value
		Lower	Upper			Lower	Upper	
Age more than or equal to 3 years	7.215	1.257	41.428	0.027*	5.419	1.329	22.099	0.018*
Female sex	6.620	1.775	24.691	0.005*	4.549	1.409	14.687	0.011*
Non-ambulating status	5.571	1.177	26.365	0.030*	8.191	2.214	30.308	0.002*
Type of CP (hemiplegia as a reference)								
Diplegia	4.504	0.542	37.466	0.164				
Quadriplegia	6.106	0.489	76.200	0.160				
Health insurance scheme (universal coverage as a reference)								
Health insurance scheme for foreigners	0.948	0.107	8.429	0.962				
Cash payment	0.294	0.061	1.414	0.127				

B, unstandardized regression coefficient; CP, cerebral palsy
*significant level at $p < 0.05$, multivariable linear regression analysis

Table 3. A simple prediction score for predicting hip subluxation/dislocation

Predictors	Range of test scores	Weighted coefficient	Minimum score	Maximum score
Age more than or equal to 3 years	0-1	1	0	1
Female sex	0-1	1	0	1
Non-ambulating status	0-1	2	0	2
Total score			0	4

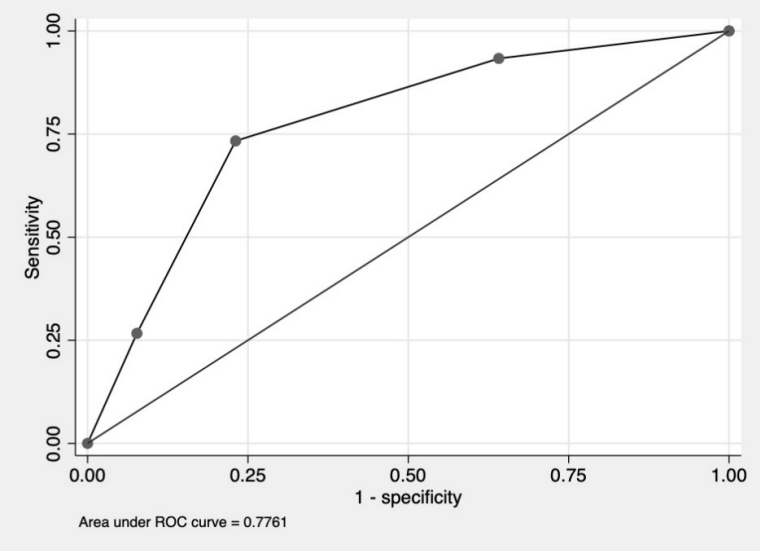

Figure 3. Area under the receiver operating characteristic curve (AuROC) of the prediction score
ROC, receiver operating curve

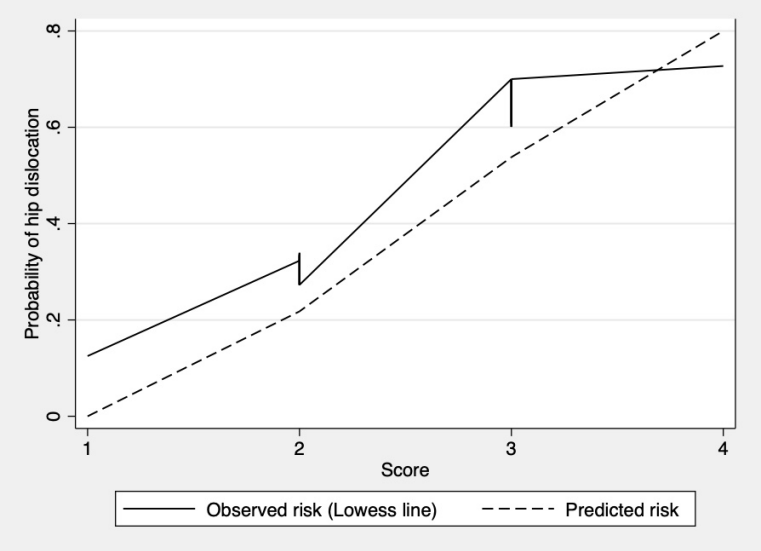

Figure 4. A calibration plot comparing the observed risk to the predicted risk from the prediction score
Lowess, locally weighted scatterplot smoothing

38.6%-66.7%), an NPV of 87.5% (95%CI: 61.7%-98.4%), and a positive LR of 1.46 (95%CI: 1.13-1.88).

Internal validation of the CPR

After applying the bootstrapping approach (200 iterations), optimism-corrected C-statistics were 0.770 (95%CI: 0.676-0.880), and the expected-to-observed ratio of the internal validation model was 1.002 (95%CI: 0.768-1.246), indicating an acceptable internal validation.

DISCUSSION

The prevalence of hip subluxation/dislocation

In this study, the prevalence of hip subluxation/dislocation was 43%, which is comparable to the prevalence reported in high-income countries such as Sweden (2) and Australia (3). However, this prevalence was lower than a previous study from Thailand (4), which reported a prevalence of 57%. This difference might be due to differences in the characteristics of the cohorts. In the present study, only 61% of the participants had GMFCS level IV and V, which indicates a risk for hip subluxation/dislocation, compared with 70% in the previous report (4). Another factor possibly responsible for this difference is the application of a screening program. In Thailand, screening for hip dislocation or dysplasia in CP is not yet widely practiced. The previous study was conducted in the Queen Sirikit National Institute

of Child Health which has a screening protocol. However, no hip surveillance protocol was applied in our setting during this study.

Predictive factors of hip subluxation/dislocation

In this study, three predictive factors for hip subluxation/dislocation were proposed, including age ≥ 3 years at screening, female sex, and non-ambulatory status indicated by a GMFCS III of or more. A previous study demonstrated that hip subluxation/dislocation usually occurs at age between two to four years (2). Therefore, participants who were screened at age ≥ 3 years may have a greater risk for developing hip subluxation/dislocation than those who were screened at a younger age. Although no explanatory mechanism was suggested, a previous study reported that female children had a higher risk for hip subluxation/dislocation than male children (8). However, other studies have not demonstrated this association (17). Further studies are needed to confirm the association between female sex and hip dislocation/subluxation. GMFCS is an established risk factor for hip subluxation/dislocation. A comparison among children with CP GMFCS found that those with levels III, IV, and V had a significantly higher relative risks of hip displacement than those with level II (2). However, there have been no studies combining these three risk factors in a single predictive model.

Performance of the prediction score: discriminative ability

The performance of CPR should be evaluated in terms of both discrimination and calibration. Discrimination, i.e., the ability of the CPR to differentiate between patients with and without hip dislocation/subluxation, can be evaluated using the AuROC. The AuROC of this CPR is 0.776 (95%CI: 0.668-0.884), indicating an acceptable discriminative ability (18). This result means that if CPR is used with 100 patients with CP, the hip subluxation/dislocation status of 78 patients would be correctly predicted. On the basis of this AuROC, CPR is appropriate for use as an assistive (used to suggest further investigation to confirm a diagnosis of hip subluxation/dislocation), not as a directive to be used alone for management planning. This discriminative ability could be improved by applying and adjusting the CPR in a larger cohort to ensure an adequate sample size and power of analysis. According to the internal validation of discriminative ability, the C-statistic of 0.770 in the bootstrap model compares well with the 0.776 value in the development model. This result indicates an acceptable increase in the discriminative ability of the CPR (13). It should be noted, however, that this is the first "diagnostic model", i.e., the first developed for predicting a diagnosis of hip subluxation/dislocation at this time point for considering referring to the hospital . Other prediction models are "prognostic models", i.e., prognosing an event in the future, not a condition at the present time (9), thus the performance of the models cannot be directly compared.

Performance of the prediction score: calibrating ability

The calibrating ability of the CPR can be evaluated by assessing the agreement between the predicted probabilities and the observed outcome frequencies in each total score (19). Calibrating ability can be evaluated by various methods, but observing and interpreting a calibration plot is one of the best methods for assessing the calibrating ability of the CPR (19). Although the predicted probability curve and the observed risk LOWESS curve are very similar, the CPR underestimates the true risk of hip subluxation/dislocation at score 0-3 but overestimates the true risk of hip subluxation/dislocation at score 4. Overestimating the risk of hip subluxation/dislocation may not be clinically meaningful; however, the estimation should be taken into consideration if the patient has a score of 0-3 since the observed probability may be higher than the predicted value. As this CPR was developed to be an assistive tool, clinicians should combine the results of the CPR with clinical contexts before judging whether the patient is at risk of hip subluxation/dislocation or not. According to the internal validation of the calibrating ability, the E:O ratio of 1.002 indicates an acceptably overestimated calibrating ability of the CPR (13).

Diagnostic indexes of the CPR

To make the CPR more clinically applicable, a cut-off level has been applied. A cut-off level ≥ 3 has been used because it provides a relatively higher specificity. However, the sensitivity is low,

creating a risk of a false negative result (20) and undiagnosed hip subluxation/dislocation. Although a cut-off level ≥ 2 has a relatively lower specificity, its sensitivity is high (93.3%), making it suitable for use as a screening tool. Even using this cut-off point, however, 3% of patients will still miss being referred for investigation (false negative). For that reason, clinicians should use this CPR as an assistive tool for deciding whether the patient should be referred for further investigation to be used together with clinical judgment and an appropriate follow-up strategy, i.e., at least yearly for patients with GMFCS I-II and every six months for patients with GMFCS III-V (4).

Limitations and risks of biases

The main limitation of the study is the small number of patients who were diagnosed with hip subluxation/dislocation. According to the TRIPOD, a minimum of 100 events and 100 non-events should be included to make a predictive model valid (14). In this study, only 30 patients with hip subluxation/dislocation and 39 patients without hip subluxation/dislocation were included. In spite of the low number of patients, the performance of the CPR was acceptable, indicating a possibility for clinical utility. This model should be used as a preliminary CPR and additional external validation studies should be conducted before applying it in actual clinical practice. Another limitation is that we used a retrospective study design, therefore, there was a risk of missing data, a situation which we decided to manage by applying complete case analysis. Additionally, As the recruitment strategy of this study was convenience sampling, it may have affected generalizability of the results as patients with CP who did not come to the hospital for screening may have been at greater risk for hip subluxation/dislocation than those who came to the hospital. Another limitation of this study is that some parameters were not evaluated, e.g., comorbidities as a predictor, as well as femoral head-shaft angle and acetabular index as an outcome assessment measure.

We assessed the risks of bias in this study using the Newcastle-Ottawa Score (NOS) for a cross-sectional study (21). The first component of NOS is selection biases, including representativeness of the sample (non-randomized sampling - 1 point), sample size (not satisfactory - 0 points), non-respondent evaluation (no summary data on non-respondents - 0 points), and ascertainment of the risk factors (hospital records only - 2 points). The second component is the comparability (confounding can be adequately controlled - 1 point). The third component is the outcome, including assessment of outcome (unblinded assessment using objective validated methods - 2 points) and statistical tests (clearly described, appropriate plus measures of association presented including confidence intervals and probability level - 2 points). The total NOS score for this study is 8 points, which is considered a good or low risk-of-bias study.

Clinical and research implications

Since this CPR uses only simple clinical predictors (age, sex, GMFCS), it should be possible to use it in extremely low-resource areas. We plan to use this CPR at outreach clinics where hip radiography cannot be accessed, such in community-level clinics in mountain areas or in temporary clinics near national borders. If the CPR score in a patient with CP is ≥ 3, indicating a high probability of hip subluxation/dislocation, that patient should be referred to a hospital where hip radiography can be used to confirm the diagnosis of hip subluxation/dislocation. However, an external validation study to evaluate predictive performance in that setting should be conducted prior to adopting this CPR in other clinical settings. In the Hip Subluxation Prevention Program for children with CP at Queen Sirikit National Institute of Child Health, it is recommended that treatment should be started in a child with GMFCS level 1-2 who has hip abduction range of motion <45 degrees together with an MP of 30-40% (4). However, in this study, the physical examination data were incomplete and therefore were not used. In future studies, it may be beneficial to include physical examination data in an updated CPR to ensure adherence to the guidelines and potentially improving its performance.

CONCLUSIONS

We introduced our diagnostic CPR for predicting hip subluxation/dislocation in patients with CP from our database including 69 patients with CP and a prevalence of hip subluxation/dislocation of 43%. This CPR may be used to evaluate the risk of hip subluxation/dislocation in settings where hip radiography cannot be accessed. Further external validation studies are needed to confirm the robustness of its performance before applying this CPR in other clinical settings.

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CONFLICT OF INTEREST STATEMENT

The authors declare that there are no conflicts of interest.

ADDITIONAL INFORMATION

Author contributions

A.K.: was responsible for designing the research question, collecting and analyzing the data, drafting the manuscript and writing the final version of the manuscript; S.P.: was responsible for designing the research question, analyzing the data, and commenting on the final version of the manuscript.

Data archiving

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Statement of ethics

The authors certify that the protocol of this analysis was approved by the Research Ethics Committee of Nakornping Hospital, Chiang Mai, Thailand, study code:016/67

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