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The Pittsburgh Impairment Testing Tool (PITT) for Spina Bifida Can Predict Ambulation and Transfer Ability in Adults with Spina Bifida

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Abstract

Objective: The aim of this study was to evaluate the predictive accuracy of the Pittsburgh Impairment Testing Tool (PITT). It was hypothesized that PITT would have a good overall accuracy (≥80%) for predicting both ambulation and transfer ability and that overall accuracy of PITT would be higher than that of other scales.

Design: A retrospective chart review was used to classify 409 adults with spina bifida according to seven neurological scales. A Naïve Bayes classifier was used to obtain accuracy estimates for predicting both ambulation and transfer ability as a function of each scale.

Results: PITT was the only scale demonstrating >80% overall accuracy for predicting both ambulation and transfer ability. While several scales demonstrated ≥80% overall accuracy in predicting transfer ability, none were useful in predicting inability to transfer. Inability to transfer was difficult for all tools to predict.

Conclusion: PITT demonstrated good overall accuracy for predicting both ambulation and transfer ability. Sensory and anatomic levels were less useful than motor level in predicting functional ability.

Keywords

Spina Bifida; myelomeningocele; Spinal dysraphism; neurologic examination; motor skills; walking; wheelchair

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Introduction:

Spina bifida is a congenital condition caused by failure of the neural tube to close.[1] It affects 1 in every 2,758 births in the United States.[2] Individuals with spina bifida can experience motor and sensory impairments of the lower limbs as well as orthopedic issues, resulting in a range of mobility from unimpaired lower limb function to paraplegia.[3] This affects the ability to transfer and ambulate, which are related to independence, employment, and health-related quality of life.[4–9]

Motor level is generally defined as the most distal intact neuro-segmental level associated with muscle function.[10] The *Guidelines for the Care of People with Spina Bifida* recommend measuring motor level using a standardized assessment tool because it is related to many health outcomes including sleep disordered breathing, obesity, and impaired mobility.[11,12] Motor level is one of the most important predictors of ambulation and transfer ability in those with spina bifida age 5 years and older[7,13] and over time as a person ages.[14,15] Moreover, muscle strength may be more important than neurosegmental lesions in predicting ambulatory ability.[10]

However, a variety of tools to measure motor level exist, and the *Guidelines for the Care of People with Spina Bifida* do not specify which tool should be used. The International Standards for Neurological Classification of Spinal Cord Injury (ISNCSCI)[16,17] was designed for traumatic spinal cord injuries but is sometimes used with non-traumatic injuries. The Broughton scale[18] and the functional level of lesion used in the National Spina Bifida Patient Registry[7] have been found to be highly correlated with ambulation ability.[19]

A new tool, the Pittsburgh Impairment Testing Tool (PITT), was found to have high content validity and clinical utility[20] but has not yet been used to predict ambulation or transfer ability. PITT involves testing of only two muscle groups which are routinely evaluated in the clinical setting: iliopsoas (hip flexion, HF) and quadriceps (knee extension, KE). Development of the tool was based upon the concept that KE strength is important for ambulatory ability,[7] and that a large number of individuals have weak or untestable ankle strength.[20]

The aim of this study was to evaluate the predictive accuracy of PITT as compared to other scales. It was hypothesized that PITT would have good overall accuracy (≥80%) for predicting both ambulation and transfer ability and that overall accuracy of PITT would be higher than that of other scales.

Methods:

This project was approved by the Institutional Review Board at the University of Pittsburgh as a retrospective chart review; the IRB waived the requirement for informed consent. A database of 409 adults with spina bifida was compiled, and data were extracted from each individual's most recent clinic appointment. The extracted variables were:

- Demographics (age, gender, race, ethnicity)

- Spina bifida sub phenotype (6 categories defined by the NSBPR[7] and "other type of occulta")
- **Ambulation ability**, as defined by Hoffer[9] and NSBPR:[7]
  - Community ambulator – Walks indoors and outdoors, often with crutches or braces or both. Uses a wheelchair only for long trips into the community.
  - Household ambulator – Walks indoors, often with crutches or braces or both. Typically uses a wheelchair for some indoor activities and for all community activities.
  - Therapeutic ambulator – Requires supervision or assistance to walk in therapy and does not walk independently in the household or in the community. Uses a wheelchair for mobility at home and in the community.
  - Non-ambulator – Uses a wheelchair at all times.
- **Transfer ability (yes/no)**, defined as the ability of the individual to transfer to all surfaces (wheelchair, bed, or chair) independently. Unlike the NSBPR,[7] which assigns transfer ability only to those who are non-ambulators, we assigned transfer ability to all participants.
- Manual muscle testing (MMT) and/or sensory testing findings in the database were used to categorize each individual using each of 6 neurological scales outlined below.

The NSBPR assigns a functional level of lesion (thoracic (flaccid lower limbs), high-lumbar (HF present), mid-lumbar (KE present), low-lumbar (foot dorsiflexion present), and sacral (foot plantar flexion present) based on the lowest level of independent movement which can be reproduced. For this analysis, two versions of the NSBPR scale were used to reflect two possible interpretations of "independent movement."[19] The **NSBPR-1** interpretation assigns an individual to a level based on muscle strength of 1/5 or greater (flicker of the muscle) while **NSBPR-3** interpretation uses 3/5 or greater strength (movement occurring against gravity but not against resistance).

The ISNCSCI[16,17] uses motor and sensory testing to categorize spinal cord injury level according to level of intact function, from C2 through S4-S5. For this analysis the two components were evaluated separately: **ISNCSCI motor** and **ISNCSCI sensory**. For the motor assessment, great toe extension (extensor hallucis longus (EHL)) is typically used to assess L5 motor strength. Orthopedic foot deformities are seen in 50.6% to 85.4% of people with spina bifida,[21] often making it difficult to test EHL. Thus; for this analysis, hip abduction was used to assess the L5 motor level, consistent with protocols used in prior studies in spina bifida.[22,23]

The **Broughton Scale**[18] assesses level of neurologic impairment according to intact and weak muscle activity in the lower limbs, categorizing individuals into 9 levels: thoracic, L1, L2, L3, L4, L5, S1, S2, and a "no-loss" level. It includes testing of tibialis posterior

(ankle inversion), peroneus tertius (ankle eversion), and gluteus maximus (hip extension), none of which are performed in our routine clinical exams. Thus, for this analysis, strength of these muscle groups was presumed to be adequate when all other criteria for a given Broughton level were also met. For example, those assigned to an S2 level are required to have gastrocnemius/soleus grade 3/5 or better, gluteus medius grade 4/5 or better, and gluteus maximus grade 4/5 or better, while also meeting all criteria for S1. Because the gluteus maximus is not routinely tested in our clinic, a level of S2 was assigned based on strength of gastrocnemius/soleus, gluteus medius, and S1 criteria.

In **PITT,**[20] strength in iliopsoas (HF) and quadriceps (KE) is graded as weak (≤3/5) or strong (≥4/5), and the individual is categorized into one of four groups: “Thoracic” is assigned for weak HF and weak KE, “HF dominant” is assigned for strong HF and weak KE, “KE dominant” is assigned for weak HF and strong KE, and “Intact” is assigned for strong HF and strong KE.

Anatomic level was defined as the highest open posterior vertebral arch.[24,25] Radiographs and neurosurgical operative reports were used to determine anatomic level but were available only for 217 individuals. For analytic purposes, the anatomic levels were grouped as Upper and Mid-Thoracic (lesion above T10), Lower-Thoracic (T10-T12), L1/L2, L3, L4, L5, and Sacral.

Statistical Analysis

Descriptive statistics were used for summarizing the data. A Naïve Bayes classifier approach was used to obtain accuracy estimates for predicting both ambulation and transfer ability as a function of each neurological scale. We chose this approach due to the high dimensionality of the data, and the algorithm’s ability to provide straightforward probabilistic prediction with very few tuning parameters. We used a 70/30 split to train the model; seventy percent of the data was used to build and train the model, and 30% was used to test how well it could classify new cases. A complete-case analysis approach to missing data was performed. Predictive accuracy was calculated for each of four ambulation categories and each of two transfer categories. Overall predictive accuracy for each scale was calculated by summing the number of individuals accurately predicted in each category divided by the total number of individuals who could be classified with the neurological scale. Data analyses were performed using IMB SPSS Modeler 18.2.

Results:

The demographic and medical characteristics of the population (n=409) are presented in Table 1 and Table 2, respectively. Age at most recent visit ranged from 20.4 to 85.7 years, with an average of 36.9 (SD 12.2) years.

Predictive accuracy for ambulation and transfer ability is shown in Tables 3 and 4, respectively. The model failed to predict Household and therapeutic Ambulation categories for all seven neurological scales. The model also failed to predict inability to transfer for five of seven neurological scales. This is due to the low frequency of these occurrences and the

propensity of machine learning algorithms to prioritize more common outcomes in order to minimize overall error.

Discussion:

This is the first study to demonstrate good overall accuracy of PITT for predicting both ambulation and transfer ability. PITT was the only scale with ≥80% accuracy in predicting ambulation ability. The NSBPR-3, NSBPR-1, Broughton, and ISNCSCI Motor scales had over 70% accuracy and the ISNCSCI Sensory and anatomic level scales had over 60% accuracy in predicting ambulation ability. All scales demonstrated ≥80% overall accuracy in predicting transfer ability, but none were useful in predicting inability to transfer. The lack of predictive capability for inability to transfer is likely due to the low frequency of this occurrence. Since this is a binary outcome, this can create a class imbalance problem where some machine learning algorithms tend to be overwhelmed by the majority class and fail to predict the minority class.[26]

Our findings underscore the fact that anatomic level and motor level are unique constructs and should not be used interchangeably. In this study, anatomic level had the lowest overall predictive accuracy for ambulation ability and transfer ability out of all scales. It is important to note that anatomic level was available for only 53% of our sample. Anatomic level is a permanent factor that is based on degree of bone formation. Motor level is based on neurological function and can vary due to deconditioning, rehabilitation, surgery, or new orthopedic or neurological issues.[27] This study's findings are consistent with findings by Rethlefsen, et al.[27] who recommended that anatomic level not be used as a measure of function.

Sensory level had lower predictive accuracy for ambulation than did any scale that measured motor function. Sensation is related to functional mobility as it is correlated with motor control. Oakeshott, et al reported that 14% of 38 children with absent sensation below L3 were community ambulators, while 0 of 42 children with absent sensation below T11 were community ambulators.[28] However, sensory level is not a common component in neurological scales used for spina bifida.[20] This study revealed that it may not be as important to measure as motor function when interested in predicting functional ability.

This study also demonstrated utility of the functional level of lesion from the NSBPR being used as a predictor for ambulation ability. Although neither interpretation of the NSBPR scale had the best overall predictive accuracy, NSBPR-1 had the best accuracy in predicting the community ambulator category, and NSBPR-3 had the best accuracy in predicting the non-ambulator category. The possible variation in interpretation of the NSBPR scale may explain these findings. For example, if a person had 3/5 strength in quadriceps and 1/5 strength in dorsiflexion, using NSBPR-1 would assign that person to the category of low lumbar, whereas using NSBPR-3 would assign them as mid lumbar. In other words, NSBPR-1 assigns a greater number of higher functional levels (i.e., lesions lower on the spine) to more people, whereas NSBPR-3 would assign a greater number of those same people to lower functional levels (i.e., lesions higher on the spine). Prior research has shown that higher functional levels (i.e., lesions lower on the spine) are positively associated with

ambulatory ability.[7,13,14] An inherent tradeoff exists in machine learning algorithms between precision (the accuracy of positive predictions) and recall (the ability to capture all positive cases). An example of a high precision, low recall model would be one that classifies few patients as community ambulators, but all of the classifications are correct. A low precision, high recall model would be one that classifies many patients as community ambulators but also includes patients who are not community ambulators. The clinical implementation of these scales must take into consideration these tradeoffs in context.

It is noteworthy that 10.5% of our cohort fell into the “Knee-extension dominant” category, meaning they have weak hip flexion and strong knee extension. We believe that proximal weakness in the presence of distal strength may represent deconditioning from muscle disuse over time and that other anatomical, neurological, and orthopedic sequalae also contribute to weakness. This may include congenital hip dysplasia and the potentially abnormal iliopsoas origin on the bifid spine. It is also important to note that spinal lesions in spina bifida are not necessarily complete transections of the spinal cord. A subset of individuals in the “Knee-extension dominant” category with deconditioning may potentially benefit from rehabilitation interventions to strengthen the HF. The PITT scale is uniquely suited to assess these patterns of weakness.

An additional important point of clarification is our use of hip abduction to represent L5 innervation, which is consistent with protocols used prior studies in Spina bifida.[22,23] Hip abduction occurs through action from the gluteus medius, gluteus minimus, and tensor fascia lata which are innervated by the L4 to S1 nerve roots.[29] Although the ISNCSCI assigns hip abduction as a non-key muscle function innervated by L4, recent literature has demonstrated that the L5 nerve root is the only root contained in both the cranial (L4 to L5) and caudal branches (L5 to S1) of the superior gluteal nerve that innervates all three hip abductor muscles.[29]

Several limitations to this study deserve discussion. First, the methods used to measure functional ability in this study are not the only measures available. For example, Swaroop and Dias[30] proposed a classification system for children that is based on motor level, bracing and assistive device use. Their scale was found to correlate well with number of steps per day.[27] We used Hoffer classification because it is the most widely used measure and because it is used in the NSBPR. Second, due to the retrospective nature of this study, some data were missing. Some orthopedic history, such as presence of congenital hip dislocation for example, was not included in this study because of the absence of radiologic imaging. However, our retrospective design allowed us to use a large population of patients. Third, the manual muscle testing data used in this study spanned a period of nearly 11 years and was collected by a physiatrist, physiatry residents, and an advanced practice provider, which may have reduced inter-rater reliability. However, the clinic’s supervising physiatrist verified all exams not independently conducted. Fourth, all patients were adults, and the majority were Caucasian, non-Latino/non-Hispanic individuals, but was similar to the demographic makeup of western Pennsylvania. This could limit external generalizability to other geographic regions. Future work is needed on using PITT in children and in understanding which demographic or clinical factors explain PITT’s ability or inability to predict functional outcomes. Finally, the models in this study involved only one predictive

factor; using multiple predictive factors, such as combining two tools (e.g., ISNCSCI motor and sensory levels), or including other medical or demographic factors, could increase predictive accuracy of the tools.

We do not intend PITT to be used in lieu of assessing ambulation or transfer ability when it is possible and clinically prudent to do so during physical examination. We believe the tool may be useful as a rouge gauge of functional ability in situations when obtaining information about ambulation or transfer ability is difficult, such as a patient having too much pain to ambulate, an environment that is inaccessible or unsafe for transfers, or a retrospective review in which ambulation or transfer data are unavailable. Future work is needed to examine the tool's ability to predict ambulation and transfer ability in a prognostic fashion.

Conclusion:

PITT is a simple, practical scale that performed as well or better than more complex scales. PITT was the only scale demonstrating >80% overall accuracy for predicting both ambulation and transfer ability. While several scales demonstrated ≥80% overall accuracy in predicting transfer ability, none were useful in predicting inability to transfer. Sensory and anatomic levels are less useful than motor level in predicting functional ability.

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What is Known:

A variety of tools to measure neurological function for spina bifida and other conditions exist. The Pittsburgh Impairment Testing Tool (PITT) was found to have high content validity, because it measures key aspects of muscle function.

What is New:

This study demonstrated that motor level is more useful than sensory or anatomic level in predicting ambulation and transfer ability in spina bifida. PITT may be a useful tool for clinical and research settings due to its good overall accuracy for predicting both ambulation and transfer ability.

Table 1.

Participant Demographics, n=409

Race	**N (%)**
White/Caucasian	388 (94.9)
Black/African-American	19 (4.6)
Asian/Asian-American	2 (0.5)
Ethnicity	
Non-Hispanic or Non-Latino	407 (99.5)
Female	223 (54.5)

Table 2.

Medical Characteristics of Population (n=409)

Spina Bifida sub phenotype	**n (%)**
Myelomeningocele	300 (73.3)
Meningocele	4 (1.0)
Fatty/Thickened Filum/Low Lying Cord	17 (4.2)
Lipomyeloeningocele	28 (6.8)
Terminal Myelocystocele	0 (0.0)
Split Cord Malformation	4 (1.0)
Other type of occulta	56 (13.7)
History of Shunting	
No	137 (33.5)
Yes	268 (65.5)
Information not available	4 (.01)
Tethered Cord Release	
No	193 (47.2)
Yes	196 (47.9)
Information not available	20 (4.9)
Chiari II Malformation	
No	125 (30.6)
Yes	112 (27.4)
Information not available	172 (42.0)
Hoffer Classification	
Community Ambulator	174 (42.5)
Household Ambulator	34 (8.3)
Therapeutic Ambulator	11 (2.7)
Non-ambulator	190 (46.5)
Able to Perform Independent Transfers	
No	60 (14.7)
Yes	317 (77.5)
Information not available	32 (7.8)
Wheelchair User	
No	141 (34.5)
Yes	266 (65.0)
Information not available	2 (0.5)
Highest Level of Bracing	
None	263 (64.3)
SMO	3 (0.7)
AFO	109 (26.7)
KAFO	13 (3.2)

Spina Bifida sub phenotype	**n (%)**
HKAFO	15 (3.7)
RGO	2 (0.5)
Information not available	4 (1.0)
PITT Scale	
Thoracic	159 (38.9)
Hip-flexion dominant	10 (2.4)
Knee-extension dominant	43 (10.5)
Intact	184 (45.0)
Insufficient information to classify	13 (3.2)

Legend:
SMO=supramalleolar orthosis, AFO=ankle foot orthosis, KAFO=knee ankle foot orthosis, HKAFO=hip knee ankle foot orthosis, RGO=reciprocating gait orthosis

Table 3.

Predicted Ambulation Ability

	Community Ambulators* (n=174)	Non-Ambulators* (n=190)	
Neurological Scale†	**Percent (Number) of Individuals Predicted Accurately**		**Overall Predictive Accuracy**
ISNCSCI Motor (n=381)	78.4% (n=127/162)	87.1% (n=155/178)	74.0%
ISNCSCI Sensory (n=409)	80.5% (n=140/174)	73.7% (n=140/190)	68.5%
Broughton Scale (n=390)	90.8% (n=148/163)	84.2% (n=155/184)	77.7%
NSBPR-1 (n=397)	91.8% (n=156/170)	81.0% (n=149/184)	76.8%
NSBPR-3 (n=397)	82.9% (n=141/170)	92.9% (n=171/184)	78.5%
PITT Scale (n=396)	88.7% (n=149/168)	91.8% (n=169/184)	80.3%
Anatomic Level (n=217)	54.7% (n=41/75)	88.6% (n=101/114)	65.4%

*None of the scales were able to predict Household (n=34) or Therapeutic (n=11) Ambulator levels. Both the numerator (correctly predicted cases) and denominator (total cases in specified ambulation category) are displayed. The prediction model discarded several cases, affecting the denominator.

†n reported is the number of individuals with sufficient information for classification by the scale and by ambulation ability.

Table 4.

Predicted Transfer Ability

	Transfer Ability (yes) n=317	Transfer Ability (no)* n=60	
Neurological Scale†	**Percent (Number) of Individuals Predicted Accurately**		**Overall Predictive Accuracy**
AIS Motor (n=352)	99.0% (n=298/301)	17.6% (n=9/51)	87.2%
AIS Sensory (n=377)	99.4% (n=315/317)	6.7% (n=4/60)	84.6%
Broughton Scale (n=359)	100% (n=305)	n/a	85.0%
NSBPR-1 (n=365)	100% (n=311)	n/a	85.2%
NSBPR-3 (n=365)	100% (n=311)	n/a	85.2%
PITT Scale (n=366)	100% (n=311)	n/a	85.0%
Anatomic Level (n=197)	82.7% (n=163)	n/a	82.7%

*Five scales were not able to predict Transfer Ability (no) category. Both the numerator (correctly predicted cases) and denominator (total cases in specified transfer category) are included for AIS Motor as the prediction model discarded several cases, affecting the denominator.

†n reported is the number of individuals with sufficient information for classification by the scale and by transfer ability.