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Using a Mathematical Model to Develop an Objective Outcome Measure for Lumbar Spine Surgery in Patients with Thoracolumbar Trauma in Nigeria

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Abstract

Background: Outcomes following thoracolumbar spine trauma in resource-limited settings are typically reported using neurological scales such as the ASIA Impairment Scale (AIS). However, these scales do not capture the functional outcomes that matter most to patients-mobility, self-care, employment and independence. This study aimed to develop a measurable, objective outcome system for use in resource-constrained Nigerian settings.

Methods: A retrospective cohort study of 237 patients who underwent surgery for thoracolumbar trauma at the National Orthopaedic Hospital Dala, Kano (January 2019 - June 2025) was conducted. Complete SCI (AIS A) occurred in 163 patients and incomplete SCI (AIS B-D) in 74. Functional outcomes-including ability to sit in a wheelchair, maintain erection (in males), use a walker, groom independently, control urine and faeces, walk independently and gain employment-were assessed at 6- and 12-months post-surgery. A logistic regression model was developed to predict the probability of achieving each functional outcome based on admission AIS grade, injury level and age.

Results: Male patients (n = 159) outnumbered females (n = 78). At 12 months, 78.5% of patients could sit comfortably in a wheelchair, 52.3% could use a walker, 38.8% achieved bowel and bladder control and only 14.3% regained independent walking. Among males, 31.4% reported ability to initiate and sustain erection. Employment return was 11.0%. The mathematical model demonstrated good predictive accuracy (AUC 0.81-0.89) for key functional outcomes. AIS grade on admission was the strongest predictor of all outcomes.

Conclusions: This study provides the first objective, multi-domain outcome system for thoracolumbar trauma in Nigeria using a mathematical model. The model enables clinicians to set realistic recovery expectations and allocate rehabilitation resources efficiently in resource-constrained settings.

Keywords: Thoracolumbar Trauma; Spinal Cord Injury; Outcome Prediction; Mathematical Modelling; Functional Recovery; Resource-Limited Settings; Nigeria

Introduction

Thoracolumbar spine trauma is a leading cause of Spinal Cord Injury (SCI) in Nigeria, with road traffic accidents accounting for the majority of cases [1,2]. The resulting neurological deficits-ranging from incomplete motor loss to complete paraplegia-have devastating consequences for patients, families and society [3,4]. In Nigeria, where rehabilitation services are limited and social support systems are fragile, the burden of SCI is particularly severe [5].

The American Spinal Injury Association (ASIA) Impairment Scale (AIS) is the standard instrument for grading neurological injury severity and predicting recovery potential [6,7]. Studies from Nigeria have reported that 61.8% of patients present with complete SCI (AIS A) and mortality at six weeks post-injury can be as high as 24.7% [8,9]. However, neurological recovery-defined as improvement in AIS grade-does not always translate into functional recovery [10]. A patient may improve from AIS A to AIS B (some sensory preservation) but remain wheelchair-dependent and unable to work.

In high-income countries, functional outcomes after SCI are routinely measured using validated instruments such as the Spinal Cord Independence Measure (SCIM) and the Functional Independence Measure (FIM) [11,12]. These tools assess mobility, self-care, sphincter control and transfers, providing a comprehensive picture of a patient's independence [13,14]. However, these instruments are often not available or validated in low-resource settings [15,16]. Furthermore, they may not capture outcomes that are particularly relevant in the Nigerian context, such as the ability to return to gainful employment, groom independently, or, for males, maintain erectile function-factors that profoundly affect quality of life and social reintegration [17,18].

A systematic review of data-driven models for SCI recovery prediction found that AIS grade, walking ability and SCIM are the most common outcome measures [19]. Recent advances in machine learning and mathematical modelling have shown promise in predicting functional outcomes after SCI, using variables such as initial FIM scores, level of injury and demographic factors [20,21]. However, no such model has been developed specifically for the Nigerian population [22,23].

This study aimed to: (1) describe functional outcomes across multiple domains-including mobility, self-care, sphincter control, sexual function and employment-in a cohort of Nigerian patients with thoracolumbar trauma; (2) develop a mathematical model to predict the probability of achieving each functional outcome based on admission AIS grade, injury level and age; and (3) propose a simple, objective outcome scoring system for use in resource-constrained Nigerian settings.

Methodology

Study Design and Setting

This was a retrospective cohort study conducted at the National Orthopaedic Hospital Dala, Kano, Nigeria - a 250-bed tertiary orthopaedic referral centre serving northern Nigeria. The study period was 1 January 2019 to 30 June 2025. Ethical approval was obtained from the institutional research ethics committee (NOHD/EC/2025/150). Individual patient consent was waived due to the retrospective nature.

Participants

All consecutive adult patients (≥18 years) who underwent surgical decompression and stabilisation for traumatic thoracolumbar spine injuries during the study period were eligible. Inclusion criteria: (1) acute traumatic injury to the thoracic (T1-T12) or lumbar (L1-L5) spine; (2) complete neurological assessment on admission using AIS; (3) surgical intervention (posterior decompression and stabilisation with pedicle screw fixation); (4) minimum 12-month follow-up; (5) complete medical and functional outcome records. Exclusion: penetrating injuries, pathological fractures and patients lost to follow-up. A total of 237 patients met the inclusion criteria: 159 males (67.1%) and 78 females (32.9%). Complete SCI (AIS A) occurred in 163 patients (68.8%) and incomplete SCI (AIS B-D) in 74 patients (31.2%).

Data Collection

Data were extracted from patient case files, operative notes, physiotherapy records and outpatient follow-up charts. Variables collected included: age, sex, level of injury (thoracic vs lumbar), AIS grade on admission and at 6 and 12 months and functional outcomes at 12 months post-surgery.

Functional Outcome Domains

Seven functional outcomes were assessed at 12 months post-surgery, based on patient interviews and physiotherapist assessments:

1. Ability to sit in a wheelchair comfortably for at least 30 minutes without support.

2. Ability to initiate and sustain erection (males only) - based on patient self-report.
3. Ability to use a walker (standard or rollator) for ambulation of at least 10 metres.
4. Ability to groom independently (washing face, brushing teeth, combing hair).
5. Ability to control urine and faeces (continence, defined as no involuntary leakage for 7 days).
6. Ability to walk independently (without assistive devices) for at least 50 metres.
7. Ability to be gainfully employed (full-time or part-time) at 12 months.

Each outcome was recorded as binary: achieved (1) or not achieved (0).

Mathematical Model Development

A multivariate logistic regression model was developed to predict the probability of achieving each functional outcome. The model was specified as:

$$\text{logit}(P) = \beta_0 + \beta_1(\text{AIS\_A}) + \beta_2(\text{Lumbar}) + \beta_3(\text{Age\_Group}) + \beta_4(\text{Time})$$

Where:

- P = probability of achieving the functional outcome
- AIS_A = 1 if complete injury (AIS A) on admission, 0 if incomplete (AIS B-D)
- Lumbar = 1 if injury level is lumbar (L1-L5), 0 if thoracic (T1-T12)
- Age_Group = 1 if age ≥50 years, 0 if age <50 years
- Time = 1 if 12 months post-surgery, 0 if 6 months (for temporal trend)

The model was fitted using maximum likelihood estimation. Model performance was assessed using the area under the receiver operating characteristic curve (AUC), Brier score and Hosmer-Lemeshow goodness-of-fit test. Internal validation was performed using bootstrapping (200 repetitions) to correct for optimism.

Objective Outcome Scoring System

Based on the model coefficients, a simple scoring system was developed, assigning points to each predictor. The total score was then mapped to the probability of achieving each functional outcome.

Statistical Analysis

Data were analysed using SPSS version 26 and R version 4.2. Continuous variables are presented as mean±SD, categorical as frequencies (%). Comparisons between groups used chi-square or Fisher's exact test. Statistical significance was set at $p<0.05$.

Results

Patient Characteristics

A total of 237 patients were included (Fig. 1). The mean age was 38.6±14.2 years (range 18-78). The majority were male (67.1%) and in the working-age group (18-50 years: 78.9%) (Table 1). Thoracic injuries (T1-T12) occurred in 141 patients (59.5%) and lumbar injuries (L1-L5) in 96 patients (40.5%). Complete SCI (AIS A) was present in 163 patients (68.8%) and incomplete SCI (AIS B-D) in 74 patients (31.2%). Table 1 presents the demographic and injury characteristics.

```
Total Patients (N = 237)
│
├── By Gender
│   ├── Male: 159 (67.1%)
│   └── Female: 78 (32.9%)
│
└── By SCI Severity
    ├── Complete SCI (AIS A): 163 (68.8%)
    └── Incomplete SCI (AIS B-D): 74 (31.2%)
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Figure 1: Patients' selection.

Characteristic	Category n (%)
Age (years) Mean ± SD	38.6 ± 14.2
18-30 years	78 (32.9)
31-50 years	109 (46.0)
>50 years	50 (21.1)
Sex	
Male	159 (67.1)
Female	78 (32.9)
Injury level	
Thoracic (T1-T12)	141 (59.5)
Lumbar (L1-L5)	96 (40.5)
AIS grade on admission	
A (complete)	163 (68.8)
B	28 (11.8)
C	26 (11.0)
D	20 (8.4)
Incomplete (B-D)	74 (31.2)

Table 1: Demographic and injury characteristics of 237 patients with thoracolumbar trauma.

Functional Outcomes at 12 Months

Table 2 presents the functional outcomes at 12 months post-surgery. The most commonly achieved outcome was ability to sit in a wheelchair (78.5%), followed by ability to use a walker (52.3%) and ability to groom independently (45.6%). Sphincter control (bowel and bladder) was achieved in 38.8% of patients. Among males, 31.4% reported ability to initiate and sustain erection. Only 14.3% of patients regained independent walking and only 11.0% returned to gainful employment.

Functional Outcome Achieved	n (%)
Ability to sit in a wheelchair comfortably	186 (78.5)
Ability to use a walker	124 (52.3)
Ability to groom independently	108 (45.6)
Ability to control urine and faeces	92 (38.8)
Ability to initiate and sustain erection (males only n = 159)	50 (31.4)
Ability to walk independently	34 (14.3)
Ability to be gainfully employed	26 (11.0)

Table 2: Functional outcomes at 12 months post-surgery (N = 237).

Outcomes by Injury Severity

Table 3 compares outcomes between complete (AIS A) and incomplete (AIS B-D) injuries. Patients with incomplete injuries had significantly better outcomes across all domains. For example, 93.2% of incomplete patients could sit in a wheelchair compared with 71.8% of complete patients ($p<0.001$). Independent walking was achieved by 31.1% of incomplete patients compared with only 6.7% of complete patients ($p<0.001$). Return to employment was 25.7% in incomplete vs 4.3% in complete ($p<0.001$).

Functional Outcome	Complete SCI (AIS A) n = 163	Incomplete SCI (AIS B-D) n = 74	p-value
Sit in wheelchair	117 (71.8)	69 (93.2)	<0.001
Use walker	68 (41.7)	56 (75.7)	<0.001
Groom independently	55 (33.7)	53 (71.6)	<0.001
Control urine and faeces	38 (23.3)	54 (73.0)	<0.001
Erection (males n = 159)*	25/111 (22.5)	25/48 (52.1)	<0.001
Walk independently	11 (6.7)	23 (31.1)	<0.001

Gainful employment	7 (4.3)	19 (25.7)	<0.001
*Erection: males only (111 complete, 48 incomplete)			

Table 3: Functional outcomes by injury severity (complete vs incomplete).

Table 4 compares outcomes between thoracic and lumbar injuries. Patients with lumbar injuries had better outcomes across most domains. Sphincter control was achieved by 49.0% of lumbar patients vs 32.6% of thoracic patients (p = 0.01). Independent walking was 21.9% in lumbar vs 9.2% in thoracic (p = 0.006).

Functional Outcome	Thoracic (T1-T12) n = 141	Lumbar (L1-L5) n = 96	p-value
Sit in wheelchair	106 (75.2)	80 (83.3)	0.13
Use walker	68 (48.2)	56 (58.3)	0.12
Groom independently	58 (41.1)	50 (52.1)	0.09
Control urine and faeces	46 (32.6)	47 (49.0)	0.01
Erection (males n = 159)*	28/95 (29.5)	22/64 (34.4)	0.52
Walk independently	13 (9.2)	21 (21.9)	0.006
Gainful employment	13 (9.2)	13 (13.5)	0.29
*Erection: males only (95 thoracic, 64 lumbar)			

Table 4: Functional outcomes by injury level (Thoracic vs Lumbar).

Mathematical Model Performance

Table 5 presents the performance of the logistic regression model for each functional outcome. The model demonstrated good to excellent discrimination (AUC 0.81-0.89) for all outcomes. The strongest predictors were AIS grade on admission (β coefficient 1.8-2.4, p<0.001) and injury level (lumbar vs thoracic, β 0.6-1.2, p<0.05). Age ≥50 years was a negative predictor for all outcomes (β -0.4 to -0.8, p<0.05). The Hosmer-Lemeshow test indicated good calibration for all models (p>0.05).

Functional Outcome	AUC (95% CI)	Brier Score	Hosmer-Lemeshow p-value	Key Predictors (β, p)
Sit in wheelchair	0.89 (0.85-0.93)	0.08	0.52	AIS A (−1.8, <0.001); Lumbar (+0.8, 0.02)
Use walker	0.86 (0.82-0.90)	0.12	0.38	AIS A (−2.1, <0.001); Lumbar (+0.6, 0.04)
Groom independently	0.85 (0.81-0.89)	0.14	0.45	AIS A (−2.0, <0.001); Age ≥50 (−0.7, 0.02)
Control urine and faeces	0.84 (0.80-0.88)	0.15	0.61	AIS A (−2.4 <0.001); Lumbar (+1.2, 0.01)
Erection (males)	0.82 (0.77-0.87)	0.16	0.33	AIS A (−1.9, <0.001); Age ≥50 (−0.8, 0.03)
Walk independently	0.81 (0.76-0.86)	0.11	0.58	AIS A (−2.2, <0.001); Lumbar (+0.9, 0.02)
Gainful employment	0.83 (0.78-0.88)	0.09	0.42	AIS A (−2.3, <0.001); Lumbar (+0.7, 0.04)

Table 5: Logistic regression model performance for each functional outcome.

Objective Outcome Scoring System

Table 6 presents the proposed scoring system. Points are assigned based on AIS grade, injury level and age group. The total score (range 0-10) is then mapped to the probability of achieving each functional outcome. For example, a patient with incomplete SCI (AIS B-D), lumbar injury, age <50 years (score 8) has a >80% probability of wheelchair sitting and >50% probability of walker use (Table 7).

Predictor	Points
AIS grade	
Complete (AIS A)	0
Incomplete (AIS B-D)	4
Injury level	
Thoracic (T1-T12)	0
Lumbar (L1-L5)	2
Age group	
≥50 years	0
<50 years	2
Total score	(0-8)

Table 6: Proposed objective outcome scoring system.

Total Score	Probability of Achieving Each Outcome (%)
	Sit in wheelchair
0-2	<50
3-5	50-75
6-8	>75

Table 7: Probability of wheelchair sitting and >50% probability of walker use.

Discussion

This study provides the first comprehensive, multi-domain functional outcome assessment for thoracolumbar trauma in Nigeria, combined with a mathematical model for predicting recovery. The findings reveal a sobering reality: despite surgical intervention, the majority of patients with complete SCI remain severely disabled, with only a minority regaining independent walking (14.3%) or returning to employment (11.0%).

The Functional Outcome Profile

The finding that 78.5% of patients could sit in a wheelchair is encouraging, as it indicates that most patients achieve a basic level of mobility and can participate in community life. However, the low rates of sphincter control (38.8%), independent walking (14.3%) and employment (11.0%) highlight the profound and persistent disability that follows thoracolumbar trauma [24,25].

The 31.4% rate of erectile function preservation among males is notable. Sexual function is often overlooked in SCI outcome studies, yet it is a major determinant of quality of life and relationship stability [26]. The fact that nearly one-third of males retained this function underscores the importance of including sexual outcomes in routine assessment.

The very low employment rate (11.0%) is particularly concerning. In Nigeria, where social security is limited and most families depend on the income of working-age members, unemployment after SCI can lead to poverty, social exclusion and deteriorating mental health [27]. This finding supports the argument that rehabilitation programmes must include vocational training and job placement support.

The Role of Injury Severity

The strong association between AIS grade and functional outcomes is consistent with international literature [28,29]. Patients with incomplete SCI had significantly better outcomes across all domains. For example, 31.1% of incomplete patients regained walking compared with only 6.7% of complete patients. This finding highlights the prognostic value of the initial AIS assessment and reinforces the importance of early, accurate neurological examination.

The Mathematical Model: A tool for Resource Allocation

The logistic regression model demonstrated good predictive accuracy (AUC 0.81-0.89) for all outcomes, making it a useful tool for clinical decision-making. In a resource-limited setting where rehabilitation services are scarce, the model can help clinicians identify patients who are most likely to benefit from intensive therapy and those who may need long-term support [30]. For example, a patient with complete thoracic SCI and age ≥50 years has a predicted probability of independent walking of <5%, whereas a patient with incomplete lumbar SCI and age <50 years has a >30% probability. This information can guide discussions with patients and families about realistic expectations and can inform the allocation of limited rehabilitation resources to those most likely to benefit.

Comparision with Other Studies

Our findings are consistent with a study from Maiduguri, Nigeria, which reported that 33.3% of patients were wheelchair-bound on discharge and only 14.8% recovered without neurological deficits [31]. A study from Jos reported that 61.8% of patients had complete SCI (AIS A) at presentation, similar to our 68.8% [8]. However, our study extends these findings by providing detailed functional outcomes and a predictive model. The low employment rate (11.0%) is comparable to international studies. A multicountry study found that employment after SCI is consistently associated with better quality of life, but rates of return to work remain low, particularly in lower-income countries [32]. A study from Pakistan reported that only 12% of SCI patients returned to work, similar to our findings [33].

Implications for Practice

1. Rehabilitation planning: The functional outcome probabilities generated by the model can be used to set realistic goals and plan rehabilitation programmes
2. Resource allocation: In settings with limited physiotherapists and occupational therapists, the model can prioritise patients who are most likely to benefit
3. Patient counselling: The model provides objective data to inform patients and families about expected outcomes
4. Vocational rehabilitation: The low employment rate highlights the need for vocational training and job placement services
5. Sexual health: The high rate of erectile dysfunction among males (68.6%) suggests that sexual health counselling should be routinely offered

Strengths and Limitations

Strengths include the large sample size (237 patients), the use of multiple functional outcome domains and the development of a predictive model. Limitations: the retrospective design; the single-centre setting; the lack of a validated functional outcome instrument (SCIM or FIM); and the absence of pre-injury functional status data. External validation of the model in other Nigerian centres is needed.

Conclusion

Functional outcomes after thoracolumbar trauma in Nigeria are poor, with only a minority of patients regaining independent walking or employment. The mathematical model developed in this study provides a simple, objective tool for predicting functional recovery and guiding resource allocation in resource-constrained settings. AIS grade, injury level and age are the strongest predictors of outcome.

Conflict of Interest

The authors declared no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

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Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Ethical Statement

The project did not meet the definition of human subject research under the preview of the IRB according to federal regulations and therefore was exempt.

Informed Consent Statement

Informed consent was obtained from all participants included in the study.

Authors' Contributions

All authors contributed equally to this paper.

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