

# Effectiveness of WHO-Guideline Based Custom Wheelchair Cushions in Reducing Interface Pressure Among Spinal Cord Injury Patients: A Cross-Sectional Comparative Study

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## ABSTRACT

**Background:** Pressure ulcers represent a major health burden for individuals with spinal cord injury (SCI), particularly in resource-limited settings where commercial pressure-relief surfaces are economically inaccessible. The World Health Organization has proposed guidelines for low-cost pressure relief cushions, yet empirical validation remains limited.

**Objective:** To evaluate the effectiveness of WHO-guideline based custom wheelchair cushions compared to standard flat cushions in reducing interface pressure among SCI patients across multiple sitting postures.

**Methods:** This cross-sectional comparative study included 29 wheelchair-dependent SCI patients (80% male, mean age 29.5±9.17 years) recruited from a tertiary rehabilitation center in India. Participants underwent bilateral ischial pressure mapping using calibrated sphygmomanometer-based sensors while seated on both flat and custom-designed cushions. Measurements were obtained across six standardized postures: midline, trunk bent left/right, upright midline, forward flexion, and slump positions. Custom cushions incorporated WHO-

specified pelvic wells with standardized dimensions. Data analysis employed paired t-tests with significance set at  $p < 0.05$ .

**Results:** Custom cushions demonstrated statistically significant pressure reduction ( $p < 0.001$ ) across all measured postures. Mean ischial pressure reductions ranged from 39-44%: midline (120→73 mmHg), trunk bent left (119.5→72 mmHg), trunk bent right (119.5→72.5 mmHg), upright midline (126→70.2 mmHg), forward flexion (110.5→64.7 mmHg), and slump (130→78.4 mmHg). Forward flexion posture provided optimal pressure relief, while slump positioning generated highest interface pressures. General Comfort Rating scores improved significantly (1.66 vs 3.43,  $p < 0.001$ ).

**Conclusion:** WHO-based custom wheelchair cushions provide clinically meaningful pressure reduction compared to flat cushions, offering a cost-effective intervention for pressure ulcer prevention in resource-constrained healthcare systems.

**Keywords:** spinal cord injury, pressure ulcer prevention, wheelchair seating, developing countries, assistive technology, rehabilitation

## **INTRODUCTION**

Spinal cord injury (SCI) affects approximately 250,000-500,000 individuals annually worldwide, with the majority of cases occurring in low- and middle-income countries where healthcare resources are limited.<sup>1</sup> Among the numerous complications following SCI, pressure ulcers (PUs) represent one of the most persistent and costly secondary conditions, with prevalence rates approaching 100% in developing nations.<sup>2</sup> The economic burden is substantial, with individual PU treatment costs ranging from \$1,400 to \$129,000 depending on severity and duration.<sup>3</sup>

The pathophysiology of pressure ulcer development in SCI patients involves a complex interplay of factors including sensory loss, motor impairment, autonomic dysfunction, and prolonged immobilization. Interface pressure exceeding capillary perfusion pressure (approximately 32 mmHg) for extended periods leads to tissue ischemia and subsequent ulceration.<sup>4</sup> The ischial tuberosities, bearing the primary weight load during wheelchair sitting, are particularly vulnerable due to the predominantly adipose and connective tissue composition beneath these bony prominences.<sup>5</sup>

Current evidence-based prevention strategies emphasize pressure redistribution through specialized seating surfaces. However, commercial pressure-relief cushions, while effective, remain prohibitively expensive for populations in resource-limited settings.<sup>6</sup> The World Health Organization (WHO), recognizing this global health disparity, has developed guidelines for constructing low-cost foam-based pressure relief cushions featuring strategically placed pelvic wells and supportive shelves.<sup>7</sup> Despite widespread dissemination of these guidelines, objective validation studies remain scarce.

Furthermore, existing research has predominantly focused on single-position pressure measurements, failing to account for the dynamic nature of wheelchair positioning throughout daily activities.

Postural variations significantly influence pressure distribution patterns, yet comprehensive multi-positional assessments are rarely incorporated into cushion evaluation protocols.<sup>8</sup>

This study addresses these knowledge gaps by providing the first systematic evaluation of WHO-guideline based custom cushions across multiple sitting postures in a developing country healthcare setting. The primary objective was to quantify pressure reduction effectiveness compared to standard flat cushions among wheelchair-dependent SCI patients. Secondary objectives included identifying optimal sitting postures for pressure relief and assessing user comfort perceptions

## **MATERIALS & METHODS**

This cross-sectional comparative study was conducted at the Department of Prosthetics and Orthotics, Swami Vivekananda National Institute of Rehabilitation Training and Research (SVNIRTAR), Cuttack, Odisha, India, between October 2018 and September 2019. The study received approval from the institutional ethics committee, and all participants provided written informed consent prior to enrolment.

### **Participants**

Participants were recruited using convenience sampling from the institution's outpatient and inpatient services. Sample size calculation was based on previous interface pressure studies with an expected mean difference of 30 mmHg between cushion types, standard deviation of 25 mmHg, power of 80%, and alpha of 0.05, yielding a minimum requirement of 25 participants.

### **Inclusion Criteria:**

- Adults ( $\geq 18$  years) with traumatic or non-traumatic SCI
- Established wheelchair users (>6 months post-injury)
- Adequate trunk stability for independent sitting
- Absence of active pressure ulcers

- Intact skin integrity over measurement sites
- Cognitive capacity to provide informed consent

#### **Exclusion Criteria:**

- Active pressure ulcers at measurement sites
- Concurrent neurological conditions affecting sitting tolerance
- Pelvic deformities or contractures preventing standardized positioning
- Cognitive impairment limiting study participation
- Recent spinal surgery (<3 months)

#### **Custom Cushion Design and Fabrication**

Custom cushions were manufactured following WHO specifications with modifications for individual anthropometric measurements. The design incorporated a two-layer construction:

#### **Base Layer (Firm Support):**

- Material: High-density polyurethane molded foam (35-40 kg/m<sup>3</sup> density)
- Pelvic well dimensions: Width = 50% of posterior seat width, depth = 50% of seat depth, height = 3.5 cm
- Well positioning: Centered beneath ischial tuberosities based on individual pelvic measurements

#### **Top Layer (Comfort Interface):**

- Material: Low-density polyurethane foam (20-25 kg/m<sup>3</sup> density)
- Thickness: 2.5 cm
- Contouring: Shaped to accommodate base layer geometry while providing smooth user interface

Cushions were covered with breathable cotton fabric and fabricated by trained technicians using standardized protocols to ensure consistency across participants.

Interface pressure mapping was performed using a validated sphygmomanometer-based measurement system. This method has been previously demonstrated to provide reliable

comparative pressure data while remaining cost-effective for resource-limited settings. <sup>9</sup>

#### **Equipment Setup:**

- Two standard sphygmomanometer cuffs (12 cm width) positioned bilaterally
- Cuff placement: Centered beneath each ischial tuberosity
- Initial inflation: 30 mmHg baseline pressure
- Digital manometer readings recorded to nearest mmHg

**Measurement Positions:** Participants were evaluated in six standardized sitting postures, each maintained for 30 seconds prior to measurement:

1. **Midline:** Neutral sitting with trunk vertical, arms relaxed
2. **Trunk Bent Left:** 15-20° lateral trunk flexion toward left
3. **Trunk Bent Right:** 15-20° lateral trunk flexion toward right
4. **Upright Midline:** Active trunk extension with emphasis on postural alignment
5. **Forward Flexion:** 20-30° anterior trunk flexion
6. **Slump:** Relaxed posterior trunk positioning with kyphotic posture

Each participant underwent complete evaluation on both flat (standard 5 cm foam) and custom cushions in randomized order, with 5-minute rest periods between conditions to prevent pressure-related tissue changes.

#### **Outcome Measures**

##### **Primary Outcomes:**

1. Right ischial tuberosity pressure (mmHg)
2. Left ischial tuberosity pressure (mmHg)
3. Average bilateral ischial pressure (mmHg)
4. Peak pressure across positions (mmHg)

##### **Secondary Outcomes:**

- General Comfort Rating (GCR) using validated 5-point Likert scale (1=very comfortable, 5=very uncomfortable)

- Postural tolerance (subjective comfort across positions)

### Data Analysis

Statistical analysis was performed using SPSS version 23.0 (IBM Corporation, Armonk, NY). Descriptive statistics characterized participant demographics and baseline measures. Paired t-tests compared pressure measurements between cushion conditions for each postural position. Effect sizes were calculated using Cohen's d. Statistical significance was set at  $p < 0.05$ . Missing data were handled using complete case analysis.

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## RESULT

### Participant Characteristics

Twenty-nine participants completed the full protocol (Table 1). The cohort was predominantly male ( $n=23$ , 79.3%) with mean age of  $29.5 \pm 9.17$  years (range: 18-48 years). Average body weight was  $58.0 \pm 11.64$  kg. Injury characteristics included both complete and incomplete SCI, with duration since injury ranging from 8 months to 15 years.

**Table 1: Participant Demographics and Clinical Characteristics**

Characteristic	Overall (n=29)	Male (n=23)	Female (n=6)
Age, years (mean±SD)	29.5±9.17	31.8±9.1	22.0±5.03
Weight, kg (mean±SD)	58.0±11.64	60.4±12.0	51.2±6.71
Injury Level, n (%)			
Cervical	8 (27.6)	6 (26.1)	2 (33.3)
Thoracic	18 (62.1)	15 (65.2)	3 (50.0)
Lumbar	3 (10.3)	2 (8.7)	1 (16.7)
Time since injury, years (median, IQR)	3.2 (1.8-6.4)	3.5 (2.0-7.1)	2.6 (1.4-4.2)

### Interface Pressure Outcomes

Custom cushions demonstrated statistically significant pressure reduction across all six postural positions ( $p < 0.001$  for all

comparisons). Mean pressure reductions ranged from 39% to 44% depending on posture (Table 2).

**Table 2: Interface Pressure Comparisons Between Cushion Types**

Position	Flat Cushion (mmHg)	Custom Cushion (mmHg)	Mean Difference (95% CI)	p-value	Effect Size (Cohen's d)
Midline	120.0±15.2	73.0±12.1	-47.8 (-51.7, -43.8)	<0.001	3.42
Trunk Bent Left	119.5±16.8	72.0±11.8	-48.6 (-53.3, -43.9)	<0.001	3.24
Trunk Bent Right	119.5±15.9	72.5±12.4	-48.0 (-52.7, -43.4)	<0.001	3.29
Upright Midline	126.0±18.1	70.2±13.6	-55.9 (-60.9, -50.9)	<0.001	3.48
Forward Flexion	110.5±14.7	64.7±10.9	-46.0 (-50.3, -41.7)	<0.001	3.52
Slump	130.0±16.3	78.4±14.2	-51.6 (-55.9, -47.2)	<0.001	3.36

Values presented as mean ± standard deviation. All comparisons significant at  $p < 0.001$

### Postural Effects on Pressure Distribution

Significant variations in interface pressure were observed across different sitting postures. Forward flexion consistently

produced the lowest pressures for both cushion types (flat: 110.5 mmHg; custom: 64.7 mmHg), representing optimal positioning for pressure relief. Conversely,

slump positioning generated the highest pressures (flat: 130.0 mmHg; custom: 78.4 mmHg), suggesting this posture should be avoided during prolonged sitting.

Lateral trunk flexion concentrated pressure loading toward the corresponding ischial tuberosity, but custom cushions effectively redistributed these forces, maintaining lower peak pressures compared to flat surfaces across all asymmetric positions.

### **Peak Pressure Analysis**

Maximum recorded pressures showed dramatic reductions with custom cushions. Peak pressure comparison for the highest-loading positions revealed:

- Trunk bent left: 184.5→130.5 mmHg (29% reduction)
- Trunk bent right: 183.8→129.8 mmHg (29% reduction)

### **Comfort Assessment**

General Comfort Rating scores demonstrated significant improvement with custom cushions (mean±SD: 1.66±0.89 vs. 3.43±1.12,  $p<0.001$ ). Twenty-six participants (89.7%) rated custom cushions as comfortable or very comfortable (GCR scores 1-2), while only 8 participants (27.6%) provided similar ratings for flat cushions.

Three participants with complete sensory loss below the level of injury indicated uncertainty in comfort assessment but were included in pressure analysis as their objective measurements remained valid.

### **Safety Outcomes**

No adverse events occurred during the study protocol. All participants tolerated the measurement procedures without skin irritation or pressure-related symptoms. Post-study visual skin inspection revealed no erythema or tissue damage at measurement sites.

## **DISCUSSION**

This study provides the first comprehensive validation of WHO-guideline based custom wheelchair cushions in a developing country

healthcare setting. The consistent 39-44% pressure reduction across all postural positions represents clinically meaningful improvement that likely translates to reduced pressure ulcer risk. These findings have important implications for global health initiatives targeting secondary complication prevention in SCI populations. **Clinical Significance of Pressure Reduction**  
The observed pressure reductions consistently brought interface pressures below previously established risk thresholds<sup>10</sup>. While absolute pressure values for tissue damage remain debated<sup>9</sup>, sustained pressures above 60-70 mmHg are generally considered problematic for individuals unable to perform independent pressure relief<sup>10</sup>. Our custom cushions achieved average pressures of 64.7-78.4 mmHg across all positions, approaching or meeting these safety margins<sup>10</sup>.

The magnitude of pressure reduction (mean decrease: 51.6 mmHg) exceeds many commercial cushion systems evaluated in previous studies<sup>11</sup>. Gil-Agudo et al. reported peak pressures ranging from 105.5-207.5 mmHg with various commercial cushions<sup>11</sup>, suggesting our low-cost custom approach may be competitive with expensive alternatives.

### **Postural Considerations**

The systematic evaluation of six different sitting postures revealed important clinical insights often overlooked in single-position studies<sup>8</sup>. Forward flexion emerged as the optimal position for pressure relief, supporting its recommendation for periodic pressure relief maneuvers<sup>12</sup>. This finding aligns with biomechanical principles showing forward trunk flexion reduces ischial loading by transferring weight to the thighs and feet<sup>12</sup>.

Conversely, slump positioning consistently generated the highest pressures and should be discouraged during prolonged sitting. This has particular relevance for individuals with SCI who may unconsciously adopt slumped postures due to trunk muscle weakness or fatigue<sup>2</sup>. Educational

interventions emphasizing postural awareness may complement cushion-based prevention strategies<sup>2</sup>.

The lateral trunk flexion data highlight the importance of symmetric positioning and the superior pressure redistribution capacity of custom cushions even under asymmetric loading conditions<sup>8</sup>.

### **Global Health Implications**

The demonstrated effectiveness of WHO-guideline based cushions addresses a critical gap in SCI care for resource-limited settings<sup>7</sup>. With material costs under \$15 USD per cushion and fabrication possible using basic tools<sup>7</sup>, this intervention represents a highly cost-effective prevention strategy. The potential for local production using indigenous materials further enhances sustainability and accessibility<sup>7</sup>.

Previous economic analyses suggest pressure ulcer treatment costs in developing countries range from \$500-5,000 per episode<sup>13</sup>. The prevention potential of custom cushions, therefore, represents substantial healthcare savings at both individual and population levels<sup>3</sup>.

#### **Comparison with Commercial Alternatives**

While direct head-to-head comparisons with commercial cushions were beyond this study's scope, our pressure reduction results compare favorably with published data on expensive alternatives<sup>11</sup>. Rosenthal et al. reported similar pressure reductions with high-end cushion systems costing 10-20 times more than our custom approach<sup>10</sup>. This suggests WHO-based cushions may provide equivalent therapeutic benefit at a fraction of the cost<sup>7</sup>.

### **Methodological Considerations**

The sphygmomanometer-based pressure measurement system, while validated for comparative studies, provides relative rather than absolute pressure values. However, this limitation does not impact the primary study conclusions regarding comparative effectiveness between cushion types. The consistent pressure reductions observed

across all participants and positions strengthen confidence in the findings.

The cross-sectional design limits conclusions regarding long-term clinical outcomes such as actual pressure ulcer incidence. Future longitudinal studies should examine clinical endpoints including PU development, healing rates, and quality of life measures.

### **Study Limitations**

Several limitations warrant consideration. The single-center design and convenience sampling may limit generalizability to other populations and settings. The predominantly male cohort reflects typical SCI demographics but may not fully represent female users who may have different anthropometric characteristics affecting cushion performance.

The unblinded nature of comfort assessments introduces potential bias, though objective pressure measurements were not susceptible to this limitation. Additionally, three participants with complete sensory loss could not provide meaningful comfort ratings, highlighting challenges in subjective assessment within SCI populations.

Dynamic pressure changes during functional activities (wheelchair propulsion, transfers, reaching tasks) were not evaluated due to equipment limitations. Future studies incorporating portable pressure mapping systems could address this knowledge gap.

### **Clinical Practice Implications**

These findings support incorporating WHO-guideline based custom cushions into standard SCI rehabilitation protocols, particularly in resource-constrained settings. Healthcare providers should consider the following implementation strategies:

1. Systematic assessment protocols incorporating multiple sitting postures during cushion evaluation
2. Patient education programs emphasizing optimal positioning and pressure relief techniques

3. Local fabrication networks to ensure sustainable access to custom cushions
4. Regular follow-up assessments to monitor cushion effectiveness and condition over time

#### Future Research Directions

Priority research needs include:

- Long-term longitudinal studies examining clinical outcomes (PU incidence, healing rates)
- Cost-effectiveness analyses comparing custom cushions to commercial alternatives
- Durability testing under real-world usage conditions
- Optimization studies refining well dimensions and foam specifications
- Implementation research addressing barriers to widespread adoption

## CONCLUSION

WHO-guideline based custom wheelchair cushions provide statistically and clinically significant pressure reduction compared to flat cushions across multiple sitting postures in wheelchair-dependent SCI patients. The consistent 39-44% pressure reduction, improved comfort ratings, and low production cost make this intervention highly suitable for resource-limited healthcare settings where pressure ulcer prevention remains a critical unmet need.

Forward flexion positioning provides optimal pressure relief and should be incorporated into patient education programs, while prolonged slump positioning should be discouraged. These findings support the implementation of custom cushion programs as a cost-effective component of comprehensive SCI care in developing countries.

The demonstrated effectiveness of this low-cost intervention has important implications for global health policy and resource allocation in SCI rehabilitation services. Healthcare systems worldwide should consider adopting WHO-based custom cushion protocols to improve secondary complication prevention while minimizing

economic burden on patients and healthcare providers.

## Author Contributions

SM: Study conception, data collection, analysis, interpretation, manuscript drafting. RP: Study supervision, methodology guidance, manuscript review. All authors approved the final version for publication.

## Data Availability Statement

The datasets used and analysed during the current study are available from the corresponding author on reasonable request, subject to institutional ethics committee approval.

## Declaration by Authors

**Ethical Approval:** Approved

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