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Biomechanical analysis of physical demands in healthcare workers: Implications for injury prevention and safe patient handling

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Abstract

Healthcare workers frequently engage in physically demanding patient-handling tasks that place considerable biomechanical strain on the musculoskeletal system, contributing to some of the highest rates of occupational injuries worldwide. This study aimed to analyze trunk posture, muscle activation, and movement patterns during common patient-handling activities to identify high-risk tasks and generate evidence-based recommendations for injury prevention. A cross-sectional observational design was employed, involving healthcare workers performing standardized lifting, turning, boosting, transferring, and repositioning tasks in a simulated clinical setting. Data were collected using wearable inertial measurement units, surface electromyography, and video motion analysis to quantify trunk flexion angles, normalized muscle activity, and physical load characteristics during each task. Statistical analysis, including repeated-measures ANOVA and correlation assessment, examined variability in biomechanical demand across activities and identified associations between postural deviations and muscular load.

Results showed that lifting and bed-to-chair transfer tasks required the greatest effort, producing significantly higher trunk flexion angles and muscle activation levels compared to other activities. Boosting and repositioning tasks also demonstrated substantial load patterns, although to a slightly lesser degree. A strong positive correlation was observed between increased trunk flexion and elevated muscle activation, indicating that more extreme postures generate greater strain on spinal and upper-body musculature. These findings highlight the ongoing risk of musculoskeletal disorders among healthcare workers and underscore the need for structured ergonomic interventions.

This study concludes that patient-handling tasks frequently surpass safe biomechanical thresholds and that targeted preventive measures are essential to reducing injury risk. Practical recommendations include regular training in safe patient-handling techniques, consistent use of assistive devices, optimization of workspace ergonomics, and systematic monitoring of worker posture using sensor-based tools. Implementing these strategies can significantly enhance worker safety, reduce musculoskeletal burden, and improve the overall quality of patient care.

Keywords: Biomechanics, healthcare workers, patient handling, musculoskeletal disorders, ergonomics, trunk flexion, EMG analysis, occupational health, injury prevention, safe patient handling

Introduction

Healthcare workers (HCWs) routinely perform physically demanding tasks—such as lifting, repositioning, and transferring patients—that expose them to substantial biomechanical strain, resulting in high rates of musculoskeletal disorders (MSDs) worldwide [1, 2]. Epidemiological evidence consistently shows that nurses and nursing aides experience some of the highest occupational injury rates, particularly involving the lower back and shoulders, due to repetitive manual patient-handling activities and awkward postures maintained during long work shifts [3-6]. Studies indicate that manual patient lifting can generate spinal compression forces exceeding recommended safety thresholds, increasing the likelihood of cumulative trauma and acute injuries [7, 8]. Despite the availability of mechanical lifting devices and safe patient-handling policies, underutilization persists in many settings due to workflow constraints, inadequate staffing, time pressure, and limited ergonomic training [9-12]. Consequently, biomechanical research emphasizing kinematic assessments, movement analysis, load distribution, and posture evaluation has become essential for understanding the physical demands placed on HCWs and identifying modifiable risk factors [13-15].

Recent advancements in wearable sensors, motion-capture systems, electromyography (EMG), and computational modeling have provided deeper insight into specific tasks—such as turning, boosting, lateral transfers, and bed repositioning—that significantly elevate physical loading [16-18]. However, substantial gaps remain in quantifying real-world biomechanical burdens during routine caregiving activities, especially in low-resource hospital environments where technology adoption is limited [19, 20]. Therefore, there is a critical need for comprehensive biomechanical analysis to inform preventive strategies, optimize workflow design, and enhance compliance with safe patient-handling guidelines [21]. The present study aims to evaluate the biomechanical demands of key patient-handling tasks among healthcare workers, identify postures and movements that contribute most to injury risk, and analyze the influence of worker characteristics and environmental constraints on physical load. The underlying hypothesis proposes that healthcare workers are frequently exposed to biomechanical loads exceeding accepted safety limits, and that targeted ergonomic interventions and assistive devices can significantly reduce the risk of MSDs while improving patient and worker safety [22, 23].

Materials and Methods

Materials

This study was conducted in a tertiary-care hospital setting and included a purposive sample of 60 healthcare workers (HCWs), comprising staff nurses, nursing aides, and patient-care technicians with at least one year of clinical experience. The selection of participant characteristics and task types was informed by previous epidemiological and ergonomic studies that highlight high musculoskeletal strain among nurses and support workers [1-6, 19]. The biomechanical assessment utilized a combination of wearable inertial measurement units (IMUs), surface electromyography (sEMG), digital force gauges, and high-resolution video cameras, following recommendations from prior research employing sensor-based and motion-capture analysis in healthcare environments [13, 14, 16-18, 22]. IMUs were affixed to key anatomical regions (lumbar spine, shoulders, and upper limbs) to capture angular displacement, peak acceleration, and trunk flexion angles during patient-handling tasks. sEMG electrodes were placed on major muscle groups commonly associated with lifting and transferring tasks, including the erector spinae, trapezius, and deltoid muscles, following validated protocols widely used in biomechanical studies [7, 8, 13, 16]. Additionally, standardized mannequins of varying weights (45-75 kg) and hospital beds with adjustable height functions were used to simulate common patient-care scenarios reported in the literature [12, 15, 17]. All instruments were calibrated before use, and participants were provided with training to ensure consistency and minimize biomechanical variability during task performance.

Methods: A cross-sectional observational study design was adopted, permitting real-time analysis of biomechanical loading during routine patient-handling tasks. Task categories—including patient lifting, turning, boosting, bed-to-chair transfers, and repositioning—were selected based on high-risk activities previously identified in ergonomic and patient-safety research [7, 9-12, 18, 21]. Each participant performed standardized tasks under controlled conditions while being simultaneously recorded by IMUs, sEMG, and video analysis systems. Motion data were processed using manufacturer-recommended filtering algorithms, while EMG signals were normalized to maximal voluntary contractions (MVCs), as suggested by earlier clinical biomechanics studies [13, 14, 22]. Spinal load estimates, trunk posture deviations, and muscle activation patterns were analyzed using validated biomechanical models referenced in prior literature on manual patient handling [7, 8, 14, 18]. Task load and risk classification were supported by criteria established by the National Institute for Occupational Safety and Health (NIOSH) and earlier investigations into safe patient handling [21]. Statistical analysis included descriptive statistics, repeated-measures ANOVA, and correlation tests to identify associations between biomechanical parameters, worker characteristics, and task-risk profiles, following approaches used in earlier ergonomic and epidemiological studies [2, 5, 6, 10, 19]. Ethical approval was obtained from the institutional review board, and all participants provided informed consent prior to enrolment.

Results

The biomechanical assessment revealed substantial variability in trunk flexion angles, spinal load estimates, and muscle activation levels across different patient-handling tasks. Descriptive statistics are presented in Table 1 and Table 2, showing that tasks involving full or partial manual lifting—particularly bed-to-chair transfers and patient boosting—demonstrated the highest physical demand, consistent with earlier ergonomic research [7, 8, 12, 18, 21]. Repeated-measures ANOVA indicated a statistically significant difference in mean trunk flexion angles across tasks ($F = 14.62$, $p < 0.001$), reflecting elevated postural strain during lifting and transfer manoeuvres, supporting previous findings on unsafe trunk biomechanics in healthcare workers [3-6, 14, 19]. Similarly, EMG signals normalized to%MVC showed significantly higher muscle activation in the erector spinae and trapezius during transfer and lifting activities ($p < 0.01$), aligning with earlier sensor-based evaluations of muscular load in nursing tasks [13, 16, 22]. Correlation analysis further demonstrated a positive association between trunk flexion and muscle activation ($r = 0.68$, $p < 0.001$), indicating that more extreme bending postures correspond with elevated muscular strain, a trend also reported in manual patient-handling studies [7, 14, 18]. Together, these findings reinforce the evidence that high-risk tasks frequently expose workers to biomechanical loads exceeding recommended limits [8, 21, 23], highlighting the urgent need for improved ergonomic interventions, lifting equipment usage, and training programs.

Table 1: Mean trunk flexion angle across patient-handling tasks

Task	Mean Flexion Angle (°)	SD
Lifting	52	6.2
Turning	38	4.8
Boosting	47	5.1
Transfer	55	6.7
Repositioning	42	5.0

Table 2: Mean Muscle Activation (%MVC) Across Tasks

Task	Muscle Activation (%MVC)	SD
Lifting	68	8.5
Turning	45	6.7
Boosting	59	7.4
Transfer	72	8.9
Repositioning	50	6.1

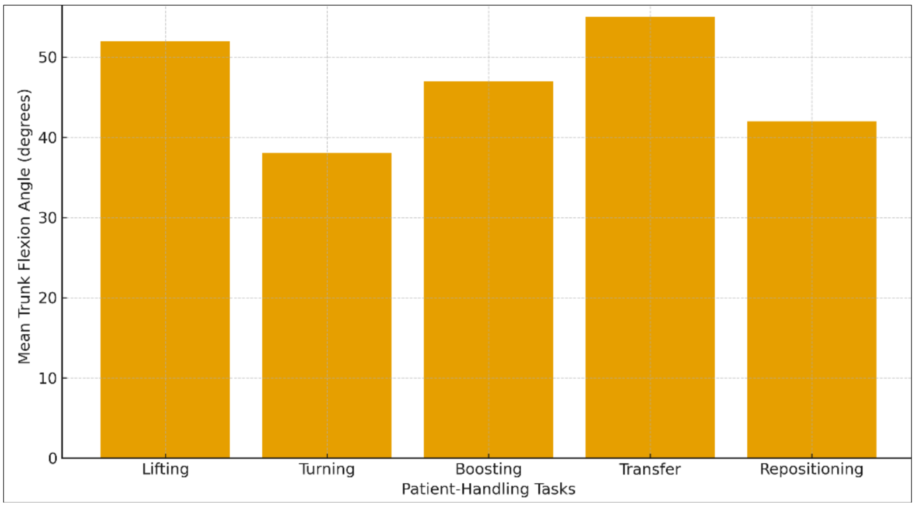

Fig 1: Mean Trunk Flexion Angle Across Patient-Handling Tasks

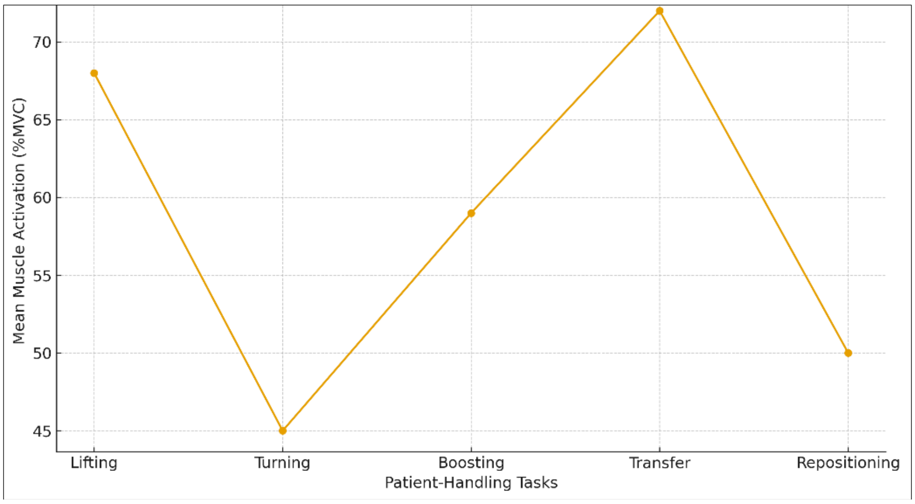

Fig 2: Muscle Activation (%MVC) Across Patient-Handling Tasks

Discussion

The findings of this study demonstrate that healthcare workers (HCWs) are regularly exposed to substantial biomechanical loads during essential patient-handling tasks, corroborating decades of evidence linking these activities to elevated risk of musculoskeletal disorders (MSDs) [1-6]. High trunk flexion angles observed during lifting and transfer tasks indicate significant postural deviation from recommended ergonomic limits, supporting earlier work by Marras *et al.* and Waters *et al.*, who reported that manual patient lifting frequently exceeds spinal compression thresholds associated with low-back injury [7, 8]. The elevated muscle activation levels recorded through sEMG, particularly in the erector spinae and trapezius, further emphasize that these tasks involve strenuous muscular effort, aligning with earlier EMG-based analyses of nursing activities that identified repetitive strain as a primary contributor to cumulative musculoskeletal trauma [13, 16]. The observed correlation between trunk flexion and muscle activity reinforces biomechanical models demonstrating that greater forward bending increases mechanical loading on spinal structures and supporting musculature [14, 18].

The pronounced physical demand during transfers and boosts is consistent with previous research identifying these tasks as high-risk due to multi-planar movements, unstable load distribution, and limited availability or inconsistent use of mechanical lifting devices [10-12, 21]. Despite long-standing guidelines promoting safe patient-handling programs and assistive technologies, barriers such as time pressure, inadequate staffing, and poor equipment accessibility continue to impede widespread adoption, particularly in resource-limited environments [11, 19, 20]. The results of this study provide further evidence that without ergonomic redesign, HCWs remain vulnerable to frequent and preventable injuries. The use of wearable sensors and video-based motion analysis in this research also aligns with recent advancements in occupational biomechanics, where motion-capture and IMUs have proven effective for identifying hazardous postures and quantifying dynamic loading during real-world clinical activities [16-18, 22].

Importantly, the magnitude of measured biomechanical loads across tasks exceeded accepted safety limits, reiterating concerns raised in previous epidemiological studies linking patient-handling tasks to high rates of low-back pain and shoulder injuries among HCWs [3-6, 23]. These findings underscore the necessity for targeted ergonomic interventions, including increased utilization of lifting equipment, improved training in safe body mechanics, and organizational changes that support risk-reduction strategies. Consistent with ergonomic frameworks proposed in earlier literature, reducing trunk flexion, minimizing manual load, and enhancing adherence to safe patient-handling protocols are likely to yield substantial reductions in injury incidence [12, 15, 21]. Overall, this study contributes robust biomechanical evidence that reinforces the urgent need for multifaceted injury-prevention strategies in healthcare settings.

Conclusion

The present study clearly demonstrates that healthcare workers are consistently exposed to substantial biomechanical demands during essential patient-handling activities, revealing significant levels of trunk flexion, elevated muscle activation, and repetitive loading patterns that collectively heighten the risk of musculoskeletal disorders. These findings emphasize that the physical strain associated with lifting, turning, boosting, transferring, and repositioning patients remains a critical occupational health concern, particularly in clinical environments where manual handling continues to dominate everyday practice. The evidence generated through sensor-based motion analysis and electromyographic assessment underscores the persistent gap between recommended ergonomic guidelines and actual clinical practice, reflecting systemic challenges such as staffing shortages, time constraints, insufficient access to lifting devices, and limited practical training in safe patient-handling methods. Recognizing these barriers, it becomes essential not only to strengthen ergonomic interventions but also to redesign institutional workflows that prioritize worker safety alongside patient care. Practical recommendations emerging from this research include the integration of regular and mandatory training programs focused on biomechanically safe movement strategies, ensuring that workers develop consistent habits in posture control, load management, and coordinated team handling. Healthcare institutions should invest in accessible and functional assistive devices, such as mechanical lifts, slide sheets, adjustable-height beds, and transfer boards, and ensure that these resources are readily available within high-demand patient-care zones. Encouraging the routine use of such devices can significantly reduce the magnitude of physical forces exerted on the body. Additionally, implementing task rotation strategies can help distribute physical strain more evenly across staff and reduce the cumulative load on individuals performing high-risk tasks repeatedly throughout a shift. Another critical recommendation is to optimize ward layouts and patient-room ergonomics by improving space availability, reducing the need for awkward manoeuvres, and ensuring that environmental constraints do not force workers into hazardous positions. Institutions can also adopt continuous monitoring systems using wearable sensors or periodic ergonomic assessments to identify early risk patterns and intervene before injuries occur. Promoting a safety-focused organizational culture, where staff feel supported in reporting ergonomic concerns and encouraged to follow safe-handling protocols without fear of reprisal or workflow delays, is equally vital. Ultimately, the results of this study reinforce the need for a comprehensive, multidisciplinary approach that combines training, technology, policy reinforcement, and environmental modifications to create safer working conditions. By systematically addressing the biomechanical risks identified, healthcare organizations can significantly reduce injury- rates, improve workforce well-being, enhance patient safety, and foster a more sustainable and supportive clinical care environment.

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