Investigating the Impact of a Treadmill Transfer Bed (TTB) on Enhancing the Safety of Patient Transfers

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ABSTRACT

Manual patient transfer is one of the most frequent activities in healthcare, yet it poses significant risks of musculoskeletal disorders for medical staff and potential injuries, such as falls, for patients. Current transfer aids often fail to adequately address these issues, necessitating a technological solution. This project introduces the design and evaluation of an innovative Treadmill Transfer Bed (TTB), a semi-automated device engineered to improve the safety and efficiency of transferring patients from one surface to another. The TTB utilizes a unique mechanism combining a motorized, low-speed, high-torque conveyor belt with a linear sliding system. This design allows a single operator to slide the conveyor surface under the patient and transfer them smoothly without any lifting or manual repositioning, thereby minimizing physical strain on caregivers and eliminating dangerous patient movements. This paper outlines the design of a prototype and proposes a methodology for its evaluation in a clinical simulation environment using standardized mannequins to assess key performance indicators such as transfer time, safety, and operator workload. The development of the TTB aims to reduce patient fall risks, decrease the need for extra personnel, and enhance the overall safety and modernization of patient care protocols.

Keywords: **Treadmill Transfer Bed, Patient Safety, Safe Patient Handling, Clinical Simulation, Medical Device Design**

1. *INTRODUCTION*

Patient transfer, the process of moving a patient from one surface to another (e.g., bed to stretcher), is one of the most common and repetitive activities in patient care. While seemingly simple, this process is a major source of occupational injury for healthcare staff and poses significant safety risks to patients. Traditional manual transfer methods often require a minimum of two strong individuals to move a patient of average weight, and this need increases with heavier patients. This reliance on human strength not only leads to inefficiencies when adequate staffing is unavailable but also results in high rates of work-related musculoskeletal disorders (MSDs) among caregivers, such as chronic back and neck pain. According to the Occupational Safety and Health Administration (OSHA), over 50% of all reported injuries among nursing assistants are MSDs stemming from patient handling.

The risks for patients are equally concerning. Manual transfers can be particularly dangerous for trauma patients, those with spinal injuries, or individuals with low levels of consciousness, where a single improper movement can lead to permanent damage. Furthermore, the process carries a high risk of patient falls and can lead to patient dissatisfaction and a loss of trust due to uncomfortable or culturally inappropriate physical contact.

1.1 Existing Solutions and Their Limitations

To mitigate these risks, numerous assistive devices have been developed. Research confirms that using such equipment can significantly reduce physical strain on caregivers and increase patient comfort. However, many existing technologies possess inherent flaws that have limited their widespread adoption and often lead personnel to revert to high-risk manual methods.

A review of prior art, including patented devices, reveals several recurring limitations. A common design flaw is the continued need for a caregiver to manually roll or reposition the patient to place a transfer board or sling underneath them. This step reintroduces the very patient movements that the device is supposed to eliminate. Other solutions utilize lifting mechanisms (similar to a crane), which present a serious risk of patient falls and often have weight restrictions, rendering them ineffective for bariatric patients. Some designs are large, scaffold-like structures that are impractical for use within the confined spaces of many hospital rooms.

1.2 The Proposed Solution: The Treadmill Transfer Bed (TTB)

To address the shortcomings of current methods, this paper introduces a novel device: the Treadmill Transfer Bed (TTB). The TTB is designed to facilitate a safe, efficient, and dignified patient transfer performed by a single operator. Its core innovation is a motorized conveyor-belt mechanism that actively slides underneath the patient and gently draws them horizontally onto the transfer surface. This process entirely eliminates the need for lifting or pulling the patient, thus removing the risk of falls and minimizing unnecessary body movements. This study presents the complete design of the TTB and outlines a detailed methodology for manufacturing and evaluating a functional prototype in a simulated clinical setting to validate its impact on patient safety and caregiver ergonomics.

2. DEVICE DESIGN AND MECHANISM

The Treadmill Transfer Bed (TTB) is engineered as a semi-automated system that integrates mechanical and manual components to achieve a safe and seamless patient transfer. The overall structure is mounted on a wheeled chassis for mobility. Its design can be broken down into its main components and its principle of operation.

2.1 Main Components

The TTB consists of several interconnected systems, as illustrated in Fig. 1 and Fig. 2.

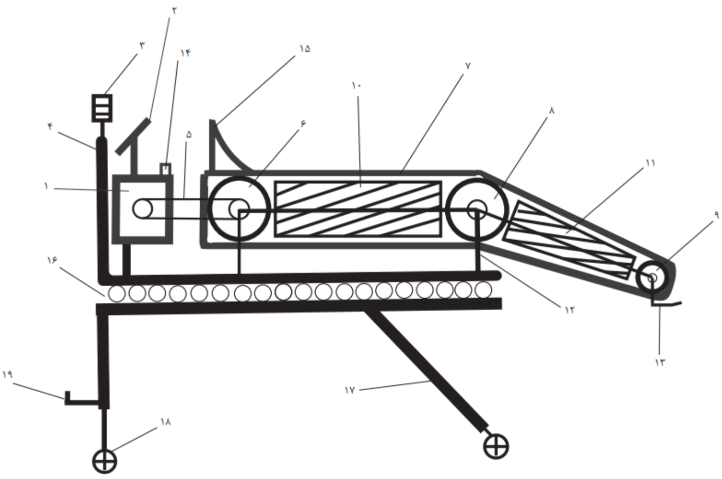

Fig.1. A side view image of the bed's overall structure, showing its main components.

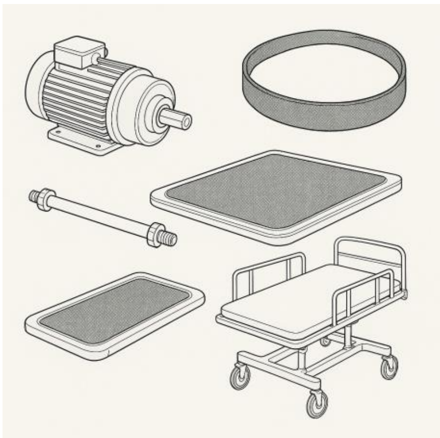

Fig.2. This image is a technical drawing of the bed's components, drawn individually. By properly connecting these components, the final bed structure can be achieved.

2.1.1 Power and Drive System

The device is powered by a high-torque, low-speed electric motor (1) similar to those used in commercial treadmills. This motor provides sufficient force to move heavy patients while maintaining a slow, safe speed. Power is transmitted from the motor to a primary drive roller (6) via a durable rubber belt (5). The entire system is powered by a standard electrical outlet.

2.1.2 The Transfer Conveyor System

This is the core of the TTB, designed to gently guide the patient onto the bed. It includes:

- ***Conveyor Mat (7):*** *The surface is made of a resistant, high-friction rubber material featuring specially designed protrusions (27) to securely grip the patient's body and prevent slipping during transfer. For patient comfort, padded mattresses (10, 11) are integrated directly into the mat's surface.*
- ***Roller Assembly:*** *The mat is supported by three main rollers. The drive roller (6) is powered by the motor to move the mat. A fixed support roller (8) maintains the structural integrity of the flat section of the bed. Critically, a third, thinner roller (9) is located at the leading edge of a sloped section, creating a tapered profile that allows the mat to slide under the patient with minimal resistance.*
- ***Leading Edge Guide (13):*** *A smooth, ski-like structure is placed directly under the leading edge to prevent the conveyor mat from catching on or bunching up the patient's bedsheets, ensuring a smooth insertion.*

2.1.3 Manual Sliding and Control System

The transfer is guided by a single operator using a manual control system.

- ***Linear Sliding Frame:*** *The entire conveyor assembly is mounted on a set of linear bearings (16), which allows the operator to manually slide it horizontally (forward and backward). This movement is controlled using push handles (3, 20).*
- ***Control Panel (2):*** *Located conveniently near the push handles, the panel includes buttons for forward and reverse movement of the conveyor, as well as an emergency stop button (14).*

2.1.4 Safety Features

Multiple features are integrated to ensure maximum safety:

- ***Safety Wall (15):*** *A physical barrier is placed between the motor housing and the patient area. If the conveyor mat moves too far, this wall makes contact with the emergency stop button (14), immediately halting the device to prevent the patient from falling off the head of the bed .*
- ***Height Adjustment (19):*** *A manual lever allows the TTB's height to be precisely matched with any hospital bed, ensuring a level transfer surface.*
- ***Stabilizing Wheels:*** *The front wheels (17) are angled to create a wider, more stable base, while all wheels (18) are lockable to hold the device securely in place during the transfer process.*

2.2 Principle of Operation

The novelty of the TTB lies in the simultaneous combination of two movements, as shown schematically in Fig. 3 and Fig. 4. To transfer a patient from their bed onto the TTB, the operator performs the following steps:

1. *The TTB is positioned and locked next to the patient's bed, with its height adjusted to be level.*
2. *The operator activates the motor via the control panel (2), causing the conveyor mat (7) to begin moving.*
3. *Simultaneously, the operator uses the push handles (3) to manually slide the entire conveyor assembly forward on its linear bearings (16).*
4. *This combined action—the forward push of the frame and the backward motion of the mat's surface—causes the thin leading edge (9) to slide under the patient while the mat's surface gently pulls the patient's body onto the TTB.*

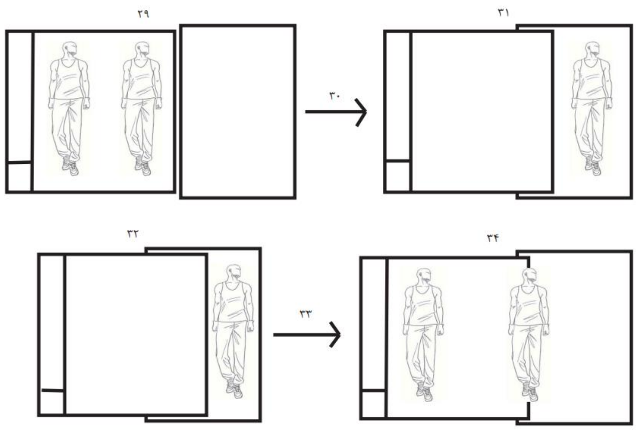

Fig.3. Schematic image of how the bed works and the method of patient transfer

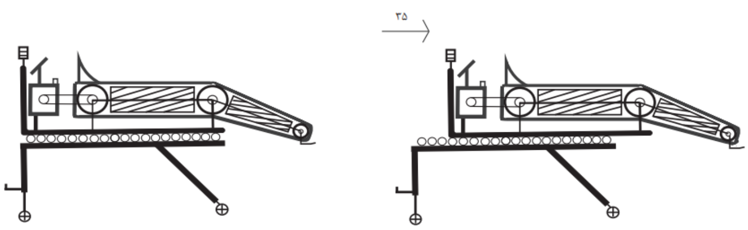

Fig.4. Image of how the sliding bed moves from the side area

This dual-motion mechanism effectively "scoops" the patient onto the transfer bed without requiring any lifting from the caregiver or repositioning of the patient, thus eliminating the primary sources of injury and risk in traditional transfer methods . The process is simply reversed to move the patient from the TTB to a destination surface.

3. METHODOLOGY FOR EVALUATION

To assess the performance, safety, and feasibility of the Treadmill Transfer Bed (TTB), a two-phase experimental study will be conducted in a controlled, simulated clinical environment. This approach allows for rigorous testing of the device's mechanical functions and ergonomic benefits before clinical trials with human subjects.

3.1 Phase 1: Prototype Development

In the initial phase, a full-scale, functional prototype of the TTB will be designed and manufactured based on the technical schematics previously described. This process involves assembling the mechanical components, including the frame, motor, conveyor system, and linear bearings, and integrating the electrical control and safety systems. The design and manufacturing will adhere to ergonomic principles and medical device safety standards.

3.2 Phase 2: Performance Evaluation in a Simulated Environment

3.2.1 Test Environment and Subjects

The evaluation will take place in a laboratory designed to simulate a standard hospital room, equipped with a standard patient bed and appropriate lighting, consistent with the principles of clinical simulation. To ensure safety and focus purely on the mechanical performance of the TTB, the study will utilize standardized human mannequins instead of actual patients. To account for patient diversity, the mannequins will be configured into four distinct test groups based on physical characteristics:

- *Group 1: Short Stature / Low Weight*
- *Group 2: Short Stature / High Weight*
- *Group 3: Tall Stature / Low Weight*
- *Group 4: Tall Stature / High Weight*

3.2.2 Sample Size

*The required sample size was calculated using G*Power software to ensure adequate statistical power for comparing the four groups. Based on a desired power of 0.80, a medium effect size (f = 0.25), and a significance level (α) of 0.05, a total of*

***80 independent transfer simulations** will be performed (20 trials per group). Each transfer process will be video-recorded for detailed analysis.*

3.2.3 Data Collection and Performance Metrics

A combination of quantitative and qualitative data will be collected to provide a comprehensive assessment of the TTB's performance. The primary metrics are:

- ***Transfer Time (seconds):** The duration from the start of the transfer until the mannequin is fully and securely positioned on the destination surface, measured using Kinovea motion analysis software.*

- ***Physical Contact Rate:*** *The number of times the operator makes direct physical contact with the mannequin during the transfer process, counted from video recordings.*
- ***Transfer Safety Score:*** *A rating on a 5-point Likert scale assigned by a trained observer to evaluate the stability and safety of the transfer, noting any instances of slipping or instability.*
- ***Operator Satisfaction:*** *The operator's perceived usability, control, and ergonomic comfort, measured using a 5-point Likert scale questionnaire adapted from established studies.*

3.2.4 Statistical Analysis

All collected data will be processed and analyzed using SPSS software (v26). Descriptive statistics, including mean, standard deviation, and frequencies, will be used to summarize the data. An Analysis of Variance (ANOVA) test will be performed to compare the performance metrics (e.g., transfer time) across the four different mannequin groups. A

p-value of less than 0.05 *will be considered statistically significant.*

4. EXPECTED RESULTS

As this study is currently in the design and preclinical evaluation phase, this section outlines the expected results based on the device's design principles and the study's hypotheses. The performance of the TTB will be quantified using the metrics defined in the methodology.

It is hypothesized that the TTB will demonstrate superior performance compared to traditional manual transfer methods. The mean transfer time is expected to be consistent and efficient across all four mannequin groups. Crucially, the transfer safety score is anticipated to be consistently high, with an expected zero instances of mannequin falls, slips, or dangerous instability during the 80 trials.

Furthermore, it is expected that the number of direct physical contacts required by the operator will be at or near zero, confirming the device's ability to perform a "no-touch" transfer. This is also expected to directly correlate with high scores on the operator satisfaction questionnaire, particularly in metrics related to perceived physical exertion, comfort, and ease of use. It is anticipated that all transfers will be successfully completed by a single operator, validating the hypothesis that the TTB eliminates the need for additional personnel. While minor variations in transfer time may be observed between the low-weight and high-weight mannequin groups, these differences are not expected to be statistically significant, demonstrating the device's robust performance across a range of patient weights.

5. DISCUSSION

The expected results suggest that the Treadmill Transfer Bed (TTB) offers a promising solution to the long-standing challenges of patient transfer. The primary contribution of this device is its novel mechanism, which replaces high-risk manual lifting and pulling with a controlled, automated horizontal transfer. This fundamentally changes the nature of the task for caregivers and significantly enhances safety for patients.

In contrast to existing solutions such as transfer boards, the TTB's design eliminates the need for caregivers to roll or manually reposition the patient to place the device, thereby removing a critical point of risk for both patient and provider. Unlike lifting systems that carry an inherent risk of mechanical failure and patient *falls, the TTB's grounded, horizontal movement provides a far safer alternative, particularly for bariatric or critically ill patients.*

The clinical and practical implications of this technology are substantial. For patients, the TTB promises a more dignified, comfortable, and less anxious transfer experience, which can improve trust and cooperation with care providers. For healthcare institutions, the most significant impact lies in staff well-being and operational efficiency. By drastically reducing the physical strain of patient handling, the TTB has the potential to lower the incidence of work-related musculoskeletal disorders, a leading cause of injury and staff turnover in the nursing profession. Moreover, enabling a single operator to safely perform a task that previously required two or more people frees up valuable human resources, addressing challenges posed by staff shortages.

This study's primary limitation is that its initial evaluation is conducted in a simulated environment with mannequins. While essential for mechanical validation, this cannot fully replicate the complexities of interacting with conscious human patients, who may experience anxiety or make involuntary movements. Future work will therefore focus on conducting the described evaluation on the prototype, followed by phased clinical trials with human subjects to assess real-world performance and gather patient feedback.

6. CONCLUSION

Manual patient transfer remains a high-risk, labor-intensive activity that compromises the safety of both patients and healthcare workers. This paper introduced the design and evaluation methodology for the Treadmill Transfer Bed (TTB), a novel semi-automated device engineered to overcome the limitations of existing methods. By employing a unique conveyor-based mechanism that eliminates the need for lifting or manually repositioning the patient, the TTB is designed to enable safe, efficient, and dignified transfers performed by a single operator. The proposed preclinical evaluation is expected to validate the device's potential to significantly reduce the risk of falls and minimize physical strain on caregivers. The TTB represents a significant step forward in patient handling technology, with the potential to establish a new standard of care that enhances safety and efficiency in hospitals and other care settings.

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