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Development of a Method for Quantifying Biomechanical Risk Factors Associated with Manual and Mechanically Assisted Patient Handling

June 2005

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RS2002/03-DG23

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WCB Grant No. RS2002/03-DG23

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Summary of Main Findings

- A novel method for quantifying biomechanical risk factors (shoulder moments and lumbar spine loading) associated with specific patient handling techniques has been developed. This method is sensitive to movement patterns and level of exertion throughout a patient handling activity.
- The older method of estimating hand reaction forces using a force matching simulation underestimates the compressive and shear loading of the lumbar spine compared to the more direct measurement of ground reaction forces using a force platform. Use of a force platform or other real-time force measurement is therefore preferred for estimating spinal stress, where practical.
- Use of an overhead lift to reposition a patient in bed takes longer than use of a slider sheet and results in greater cumulative load at the low back.
- Eliminating the need to turn a patient to install a repositioning sling or slider sheet reduces exposure to peak shoulder moments and lumbar spine loads, reduces the amount of time required to reposition a patient, and reduces the cumulative loading of tissue associated with repositioning. This supports the need to install either a repositioning sling or slider sheet as a component of bed linen replacement for patients who are dependent on a caregiver for repositioning in bed.

Executive Summary

Overexertion from patient handling activities is the most common cause of injury among healthcare workers in British Columbia (BC) and elsewhere. Increased availability and use of mechanical lifting devices has reduced the incidence of injury associated with patient transfers but has not had the same impact on repositioning tasks. There is very little objective information comparing injury risk associated with the use of overhead lifting equipment and other methods of patient handling. Understanding the correct utilization of these devices and the associated risks is imperative for prescription of best practices and evidence-based education for healthcare workers.

This project developed methods for estimating biomechanical risk associated with patient handling activities, and trialed these approaches for objectively comparing use of a slider sheet (manual) with use of an overhead lift (mechanically assisted) for repositioning patients in bed. Two biomechanical approaches were developed, using either measurement of forces beneath the caregiver's feet (ground reaction forces – force platform method) or forces at the caregiver's hands (hand reaction forces – force matching method) as input variables to a linked segment model of the human body. The dynamic position of each body segment was captured using an eight-camera digital motion analysis system. Both approaches provide an estimate of compressive and shear loading of the lumbar spine, which are indicators of injury risk to the back. Under the conditions of this project, the use of hand reaction forces underestimated peak compressive loads at the spine by 6% to 32%; however, this approach also provided an indication of injury risk to the shoulder by estimating shoulder moments. In addition to peak tissue loads, the cumulative load was estimated by integrating the load magnitude by the duration of the activity. Larger cumulative loads have been associated with increased risk for back injury.

The manual repositioning technique (using a repositioning sheet) was faster to execute than the mechanically assisted technique (using a ceiling lift). The peak moments at the shoulder and peak

compressive loading were similar for the task components of manually repositioning and for turning patients. Turning patients is required for placement of a sling or slider sheet and may be a component of either the manual or mechanically assisted task. Shear was greater for turning the patient than for manually repositioning up or across the bed. Higher peak loading and moments are believed to indicate a greater physical demand on the tissues and an increased probability of injury. The longer duration of the mechanically assisted techniques resulted in greater cumulative stress than estimated for the manual techniques (approximately 11000 Ns for mechanically assisted versus 3500 Ns for manual repositioning).

Practical application of these findings to clinical practice includes reducing the injury risk associated with repositioning patients by maintaining a sling or slider sheet beneath the patient as part of the regular activity of changing bed linens rather than placing the slider sheet or sling when patient repositioning is required. This will minimize the number of times that a patient is turned, reduce exposure to peak and cumulative loads for both manual and assisted repositioning techniques and reduce the amount of time required to perform these activities. The larger peak loads and moments associated with manual repositioning suggest that the use of an overhead lift presents less risk of injury than use of a slider sheet; however, the larger cumulative loads associated with mechanically assisted repositioning suggest the opposite. Both high peak loads and high cumulative loads have been associated with increased risk of injury. The inability to clearly distinguish the relative risk of injury between the mechanically assisted and manual repositioning methods is consistent with experience in the health care industry in which the installation of overhead lifts has not had the anticipated impact on reducing injuries associated with repositioning.

Clear, evidence-based guidance for best practices is needed in the healthcare industry to help control both the financial and human cost of injuries associated with patient handling. The development of best practices that reflect the availability of mechanical assists for lifting, transferring and repositioning patients has been hindered by a lack of guiding scientific evidence, and a subsequent lack of consensus regarding best practices among health and safety leaders in the industry. The objective biomechanical methods developed in this project to evaluate manual and mechanically assisted patient handling techniques can provide locally relevant scientific evidence that can be applied to guide decision making regarding best practices.

Further research is required to refine and to apply the analytical methods that were developed during this project to a systematic analysis of both commonly used and controversial patient handling techniques. Future research is required to establish and validate a biomechanically and physiologically valid approach to quantifying the risk of injury to health care workers, based on knowledge of their work activities. Establishing this approach will also require further research to quantify a relationship between cumulative loading and incidence of injury to health care workers. This biomechanical approach holds the potential for adding a valuable quantitative risk assessment in the development of evidence-based patient handling best practices. A holistic approach to patient handling risk management will integrate biomechanical risk assessment with psychosocial, bio-psychological and clinical considerations.

Table of Contents

Acknowledgements

This research was completed with funding from the Workers' Compensation Board of British Columbia, Research Secretariat, Grant No. RS2002/03-DG23 and in-kind contributions from the Occupational Health and Safety Agency for Healthcare in BC (OHSAH) and the Dr. Tong Louie Living Laboratory. The project was a collaborative effort involving the Institute of Health Promotion Research at the University of British Columbia, the Dr. Tong Louie Living Laboratory (Simon Fraser University and British Columbia Institute of Technology), and OHSAH. Patient handling equipment was supplied by St. Paul's Hospital and Shoppers HomeHealthCare (Waverly Glen).

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Thanks are due to the healthcare workers who volunteered their valuable time and experience to participate in the experimental phase of this project.

Research Issue and Context

In British Columbia (BC), the health care sub-sector injury rate continues to be higher than the average for all industries combined. The injury rates in 2001 for the acute care and long term care sectors were 6.4 and 10.7, respectively, and the injury rate for all industries in BC was 3.7 (Workers' Compensation Board of BC, 2002). From 1997 to 2001, overexertion from patient handling activities was the most common cause of health care injury, representing 34% of all claims (Workers' Compensation Board of BC, 2002).

These statistics for the BC health care industry are consistent with studies carried out in hospital and institutional settings elsewhere. Back injury and back pain have long been acknowledged as common musculoskeletal problems of health care professionals such as nurses, nursing assistants and physiotherapists (Bork et al., 1996; Fuortes et al., 1994; Knibble & Friele, 1996; Yassi et al., 1995). All of these professions engage in patient lifting and transferring activities. Studies looking at the incidence of back injuries in the same professional groups report a range of 25% over a two year period (Yassi et al., 1995) to 45% in a one year period (Smedley et al., 1995), indicating that a significant number of health care workers are at risk of musculoskeletal injury. The number of back injuries within these professions tends to be higher in the younger age groups (Knibbe & Friele, 1996; Ono et al., 1995).

Nurses in a university hospital reported taking an average of 16.5 days off per year as a result of back injury (Fuortes et al., 1994). In a study on ergonomics in the workplace of nursing assistants, 10% of nurses surveyed had lost one to seven work days due to back pain in the past three years and 25% had lost greater than eight days in the same time period (Garg et al., 1992). Of 1659 nurses responding to a survey, 10% had been absent from work for a period of four weeks or more due to back pain (Smedley et al., 1995).

The most common causes cited for back injury among health care professionals were incidents related to patient handling (Agnew, 1987; Bork et al., 1996; Knibbe & Friele, 1996; Garg et al. 1992; Smedley et al; 1995; Yassi et al., 1995). Engels et al., (1996) identified poor facility layout, awkward postures, lifting and stooping as factors that contributed to back injury in long-term facilities and home care. Yassi et al. (1995) reported that the most serious injuries occurred during lifts, and identified lack of training in proper lift and transfer techniques as a contributing factor to low back injury. Smedley et al. (1995) clearly identified manually moving patients on beds, lifting patients from the floor, and transferring patients from chair to bed as contributing factors to back injury.

Vasiliadou et al. (1995) reported that repositioning patients in bed was responsible for 29% of all low back injuries to nurse's aides. Owen et al. (1992) and Garg and Owen (1992) found that repositioning a patient in bed was perceived to be the second most stressful task for nurse's aides next to patient transfers. The average annual claims costs, number of claims, and time loss associated with repositioning was found to be similar to those associated with lifts and transfers in one facility (OHSAH 2000).

Garg et al. (1992) performed biomechanical analysis of nurse aid's activities, and reported that the required duties could not be dealt with safely solely through proper use of body mechanics and manual patient handling techniques. Garg was of the opinion that assistive devices were necessary to reduce stresses on the back; however, he noted that staff may be reluctant to use available assistive devices for a variety of reasons, including: lack of space, additional time requirements, lack of training, and patient fear. Schibye et al. (2003) determined that careful selection of best practices for manual patient handling can reduce the peak tissue forces to an acceptable level (below the 3400 N guidance level of Waters et al., 1993); however, it was also noted that the best practices tended to increase the duration of the patient handling. The effects of increasing the duration of loading, or cumulative load, were not evaluated. Elford et al. (2000) performed a biomechanical analysis of manual patient handling with and without slings, and concluded that the elimination of manual patient handling was the best option for controlling back injuries related to patient handling.

Efforts to curb the incidence of patient handling injuries have included the adoption of 'no manual lifting' policies (Monaghan et al., 1998), and recommendations for mechanical lifting devices to minimize the physical demands on staff performing this task (Marras, 1999; Garg et al., 1992). In BC, a memorandum of understanding (MOU) between the Association of Unions and the Health Employers Association of BC (HEABC) was signed in 2001 to prevent unsafe manual lifting of patients, and to facilitate the implementation of evidence-based practices. The provincial Ministry of Health Services has provided $15 million to support increased utilization of mechanical lifting devices and electric beds, and the Workers' Compensation Board of BC has committed an additional $6 million to support this initiative. These collaborative efforts have greatly increased the availability of mechanical lifting assists in the BC health care industry.

The use of mechanical lifting devices has reduced the frequency and severity of injury associated with patient transfers; however, despite increased availability of mechanical lift assists, the rate of injury associated with repositioning patients in bed does not appear to have declined and there has been a hesitancy among nurses and nurse's aides to use overhead lifts to assist with this task (OHSAH 2002; Engst et al., 2003).

Engst et al. (2003) reported an increase of 53% in claims costs for injuries related to repositioning after the installation of overhead lifts in one extended care facility. The staff in this facility reported that overhead lifts required more time than manual methods of repositioning, and only 34% of staff preferred to use an overhead lift when repositioning. Villeneuve (1998) and Ronald et al. (2002) also reported that overhead lifts did not influence injury incidence related to repositioning, and that overhead lifts may not be suitable for this task.

There is very little information regarding the effectiveness of overhead lifting equipment or comparing the biomechanical risk associated with the use of overhead lifting equipment with other methods of patient handling. Daynard et al. (2001) reported that the use of mechanical assists reduced peak compressive and shear forces in the lumbar spine, but increased cumulative loading due to the increase in time required to perform the task with the assist. Zhuang et al. (1999) also found that assistive devices used to transfer patients reduced biomechanical stresses on the caregiver by up to two thirds when compared to manual transfer methods, but found that the level of biomechanical stress was still dependent on technique and selection of assistive device. It is imperative that we understand the correct utilization of these devices, and the associated risks, to be able to prescribe best practices and to provide evidence-based education for the people who implement these best practices. Carefully conducted biomechanical analysis of patient handling tasks can be of use in guiding the selection of best practices.

Important factors in examining the biomechanics of lifting and moving loads are generally considered to include: characteristics of the load; range of motion during the lift; lifting technique (e.g., asymmetry); posture (e.g., trunk flexion and rotation); position of the load relative to the lumbo-sacral joint (L5/S1); foot placement; frequency or repetitive nature of the activity; and the duration of the activity (Marras, 2000; Marras et al., 1995; Waters et al., 1993; Garg, 1992). Similar factors have been identified as presenting risk to health care workers when lifting and transferring patients (Marras et al., 1999; Garg et al. 1991) and have been considered in the development of subjective instruments for evaluating patient handling techniques through simple observation (Johnsson et al., 2004; Warming et al., 2004). The use of more objective biomechanical models that account for these factors has been used to estimate peak compressive and shear loads at the lumbar spine for a variety of patient handling techniques (e.g., Marras et al., 1999; Zhuang et al., 1999). However, comparison of manual patient handling techniques with mechanically assisted techniques of longer duration requires not only an analysis of peak loading, but also consideration of cumulative loads at the lumbar spine to adequately represent the relative risk associated with these activities (Daynard et al., 2001; Norman et al., 1998; Kumar, 1990). Consistent with injury models that are based on fatigue failure of tissue (e.g., Sandover, 1983; Morrison et al., 1997), activities with larger cumulative loads have been associated with an increased risk of musculoskeletal injury (Seidler et al., 2001; Norman et al., 1998; Kumar, 1990).

In practical application, biomechanical assessment must be integrated within a broader context that also considers psychosocial factors and organizational culture. Stressful working conditions influence musculoskeletal outcomes and that there was a synergistic effect between physical factors (biomechanics) and psychosocial aspects (Daraiseh et al., 2003; Marras et al. 2000). Thus, risk management should address both the biomechanical and psychosocial aspects, and their integration.

The current project evaluated the use of biomechanical analysis systems at the Dr. Tong Louie Living Laboratory for the assessment of biomechanical risk associated with a variety of patient handling activities, and trialed this approach for objectively addressing a current concern in the BC health care industry: the use of overhead lifts for repositioning patients in bed.

Research Objectives

The primary objectives of the project were to investigate standardizable methods of quantifying biomechanical variables that would be scientifically valid and reliable, and robust enough to allow for comparative evaluation of a wide variety of patient handling scenarios. To obtain these objectives, the technical method of evaluation must not hinder performance of the primary task (patient handling) and must be practical for examination of manual handling practices, manually assisted practices (e.g., slider sheets), and mechanically assisted practices (e.g., overhead lifts). The analytical output must provide data that allows for objective comparison of the risk presented by multiple patient handling techniques.

The specific objectives of this project included the following:

1. Develop methods for biomechanical estimation of tissue loading in the shoulder and low back during simulated patient handling activities.
2. Compare the effectiveness of two different biomechanical modeling approaches that utilize either a 'top-down' (reaction forces input at the hand from force-matching simulations) or a 'bottom-up' (reaction forces input at the feet from measurement with a force platform) analytical method.
3. Evaluate the effectiveness of these methods by preliminary analysis of manual and mechanically assisted patient repositioning tasks.
4. Utilize the knowledge gained to formulate a research plan that would support a thorough biomechanical analysis of patient handling activities, and that would be of use in establishing evidence-based best practices for the use of mechanical assists, transfer devices, and manual patient handling.

Methodology

Research Subjects

Five volunteers with at least one year of clinical experience performing patient handling tasks participated in the research. Participants were in good physical health with no history of cardiovascular disease or musculoskeletal problems. All participants were informed in writing about the research procedures and provided written informed consent prior to the experiments. Participants received an honourarium of $100 for their involvement.

Table 1. Demographics of experimental volunteers.

Characteristic	**Min**	**Max**	**Mean**	**Standard Deviation**
Age (y)	26.5	48.3	38.3	7.9
Height (cm)	156.8	175.8	162.9	8.0
Weight (kg)	61	85	74.3	10.3
Patient handling experience (y)	2.5	22	14.3	7.7

Facility and Apparatus

The research was conducted in the Dr. Tong Louie Living Laboratory located on BCIT's Downtown Campus. The Living Lab is a unique full-scale simulation facility that engages in applied research and development (R&D) activities focusing on the technological, product, and environmental needs of older adults, persons with disabilities, and health care personnel.

The lab was configured to resemble a typical hospital room, complete with an electric bed and an overhead lift (TransActive – Manual, Waverly Glen) supported by a portable frame. Passive reflective markers were attached to participants using medical grade adhesive discs (3M) over anatomical landmarks (Figure 1). Positions of the markers were captured in real time using an eight-camera digital motion capture system (Peak Performance Technologies, Englewood, CO), with a sampling rate of 60 Hz. A Bertec 4060-10 multicomponent force plate (Bertec, Columbus, OH, USA) measured the ground reaction forces continuously during each trial. Peak and mean reaction force at the hands was measured during force-matching simulations using a Chatillon CSD300 hand-held digital dynamometer (Ametek, Largo, FL, USA).

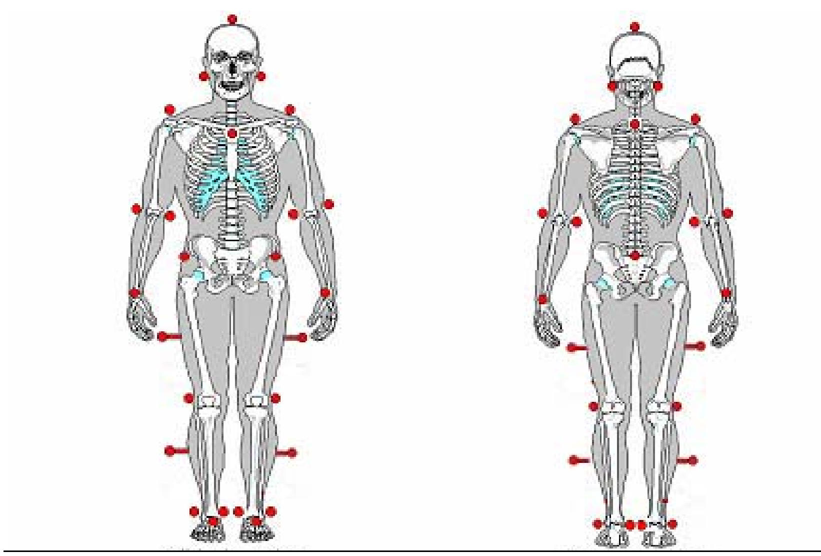

Figure 1. Reflective marker placement.

Experimental Procedures

Overview

The experimental protocol was approved independently by UBC, SFU and BCIT ethical review committees, and was carried out according to ethical guidelines consistent with Tri-Council Policy Statement (TCPS) on Ethical Conduct for Research Involving Humans. Testing sessions took approximately four to six hours, including rest and refreshment breaks.

Two commonly occurring patient repositioning tasks were evaluated (reposition up in bed; reposition laterally in bed) and two different techniques were evaluated for each of these tasks (manual technique using a repositioning sheet; mechanically assisted technique using an overhead lift) for a total of four conditions. Each technique was repeated three times by each participant.

The role of a passive patient, unable to assist or to support body weight, was played by the same member of the research team (female; 60 kg weight; 165 cm height) for all trials to maintain consistency. Both manual and mechanically assisted repositioning techniques were performed using two people, with the same researcher acting as the second person in all trials.

Due to the need for a distinct task simulation to estimate hand reaction forces for each task component that involved forceful exertion, and to provide the research team with the ability to evaluate variations in technique (e.g., use of an overhead lift with and without a sling previously installed as part of the bedding), the mechanically assisted techniques were performed as a series of task components, with each task component repeated three times. Table 2 provides a matrix of tasks and the task components that were evaluated in each trial.

Task simulations were performed immediately after each task or task component that required forceful exertion to allow for estimation of loading at the hands using a force-matching protocol (see below). The deconstruction of tasks into task components allows for further analysis of variations in technique. For example, this allows for a comparison of cumulative and peak loading associated with placing a sling beneath the patient and then repositioning up in bed versus maintaining a sling beneath the patient and repositioning up in bed. These two scenarios differ in whether the task components for turning the patient away and turning the patient towards are included in the task reconstruction.

Table 2. Overview of patient handling tasks and experimental trials.

Patient Handling Task	Discrete Trials – Task Components	Frequency
Manual repositioning up in bed	Complete task	3
	Simulated task – force matching (both hands)	3
Manual repositioning across bed	Complete task	3
	Simulated task – force matching (both hands)	3
Mechanically assisted repositioning	Turning patient away and placing sling	3
	Simulated turn away – force matching	3 left 3 right
	Turning patient towards and placing sling	3
	Simulated turn towards – force matching	3 left 3 right
	Hooking sling to overhead lift	3
	Moving up and across the bed	3
	Complete task	1
Total number of trials per subject		37

The sequence of patient handling tasks was performed in a pseudo-random order, determined first relative to manual versus mechanically assisted techniques, and second relative to either across or up in bed for the manual technique. A matrix of six different task sequences was generated and participants were randomly assigned to a specific sequence to control for order effects that may confound the way in which participants performed the tasks.

Quality Control

Quality control was implemented during experiments to improve consistency between trials and to minimize the influence of confounding variables.

Consistency in the postures assumed by the subject and in the distance that the patient was moved during the repositioning task was established by clearly marking the location of the bed relative to the force platform, and by clearly identifying a starting position and a target zone for the final position of the repositioning sheet. The start and target zones were sewn into the bed sheet with coloured thread to ensure that the movement distance was consistently between 15 and 20 cm for up in bed, and for across the bed.

Observers monitored the specific technique utilized during each trial to ensure that the subject's feet were on the force platform, that there was no significant contact between the subject's legs or torso and the bed, that there was no evidence of vertical lifting (e.g., shoulder shrugging), and that all other aspects of the technique were followed according to protocol. Any indication that the technique varied from the intended technique warranted that the trial be repeated. All subjects were provided an opportunity to practice techniques prior to data collection.

Estimation of Hand Forces – Force Matching Task Simulations

Use of a linked segment biomechanical analysis of the upper extremities and estimation of shoulder moments requires the magnitude and direction of reaction forces at the hands as an input parameter. A reliable method of continuously measuring hand forces during the performance of a patient handling task was not available, and there were concerns that the instrumentation required to measure hand force may influence the subject's posture and body mechanics. Therefore, a force-matching task simulation was performed to quantify hand reaction forces.

Immediately after each experimental trial, the subject was asked to repeat the physical effort using a Chatillon CSD300 hand-held digital dynamometer (Ametek, Largo, FL, USA) to measure force during a task simulation. During task simulations, a climbing harness or belt was used to attach the dynamometer to the patient at a location as close to the point of force application in the experimental trial as was possible. The subject was asked to perform the forceful component of the task using the same amount of physical effort, in the same direction and using as close to the same body posture as they recalled from the experimental trial. Three force matching trials were performed for each experimental condition.

Three reflective markers were attached to the Chatillon dynamometer to determine the orientation of the dynamometer relative to the subject's hand and forearm. The force vector was assumed to act along the primary axis of the dynamometer. The peak and average (5 second) magnitude of the force vector was read from the dynamometer. The peak force magnitude was used as a conservative estimate of the force required throughout the task.

Biomechanical Analyses

The position of reflective markers recorded by the video cameras was converted into three-dimensional reference points using direct linear transformation, a mathematical technique commonly used to locate spatial points filmed with two or more cameras (Marzan and Karara, 1975)

The Helen Hayes marker system, commonly used in biomechanical gait analysis, was applied to predict lower body segment parameters (mass, center of mass, moment of inertia) based on simple geometric modeling combined with anthropometric data (Vaughan et al., 1999; Chandler et al, 1975). Regression equations necessary for predicting upper body segment parameters were derived using the approach of Vaughan et al. (1999), assumptions of cylindrical or conical geometry for respective anatomical segments, and the anthropometric data of Chandler et al. (1975). Segment lengths and circumferences were measured for each subject using standard anthropometric techniques and input into the PEAK Motion Capture System. Euler angles defined body segment orientation relative to a global reference system (Goldstein, 1965)

Kinematics were calculated for each of the three anatomical planes of movement. Kinetics were calculated using two independent assumptions that utilized either ground reaction forces measured at the force plate (bottom-up kinetics) or reaction forces at the hand estimated from force-matching trials (top-down kinetics). Three-dimensional external moments and intersegmental joint forces were determined using a linked segment model, reaction forces at either the feet or hands, and inertial properties of the limb segments. Moments and forces were transformed into the local coordinate system to express the peak and cumulative shear and compressive loading at the L5-S1 intervertebral joint and peak moments at the shoulder joint to allow comparison with scientific guidance that is related to the likelihood of injury and tissue properties. Cumulative loading was estimated using a linear integration of tissue stress across the entire duration of the task (i.e., compressive load x time, shear load x time).

Statistical Analyses

Mean and standard deviation were computed for force and moment estimates for all conditions. A two-factor ANOVA with replication (alpha = 0.05) was applied to compressive and shear load estimates to compare results obtained using the top-down (hand-reaction forces) versus the bottom-up (foot-reaction forces) biomechanics. A Student's t-test was applied to compare peak load estimates for turning a patient versus sliding a patient to determine whether there was a difference in peak tissue loading between manual techniques, which include both sliding the patient and turning the patient, and use of an overhead lift, which does not involve manually sliding the patient.

Research Findings

Objective 1: Development of Methods

As a development project, the initial research findings pertain to the development of methods. This involved establishing general experimental and analytical methods that would allow the collection of meaningful data for a broad variety of patient handling tasks. This included the following key activities:

- Constructing and equipping a laboratory space that simulates a patient handling environment (electric bed; linens; overhead lift; slings and repositioning sheets) yet allows for the use of an eight-camera motion capture system and a force platform;
- Deriving an upper torso biomechanical model for the PEAK motion analysis system that would integrate seamlessly with the existing lower torso biomechanical model;

- Defining a force-matching protocol to estimate reaction forces at the hands while volunteers perform carefully controlled task simulations;
- Defining protocols for consistently training volunteers and for maintaining quality control over patient handling technique during experimental trials; and
- Defining standard data collection protocols that provide anthropometry, reaction forces at the feet, reaction forces at the hands, and body segment position during patient handling simulations.

Methods development required specific protocols to assess the manual and mechanically assisted repositioning techniques that were evaluated, including:

- Deconstructing each repositioning technique into distinct task components to allow force matching for each component;
- Detailed criteria to ensure consistency in the performance of each task component; and
- Configuration of harnesses to attach the force gauge to the patient during force matching simulations.

There are several challenges and limitations in use of a force platform, application of force matching protocols, and use of motion capture technologies that should be considered in applying these methods in future. Use of the force platform has several limitations:

- Volunteers must maintain both feet on the force platform throughout the patient handling task. This is a challenge with a small force platform and is not practical for some techniques that require a broad foot stance or that require lateral movement along the bed.
- Volunteers must be supported entirely on the force platform and must not brace against or lean on the bed while performing patient handling. This excludes the analysis of certain patient handling techniques, such as repositioning with one knee on the bed.

- A single force platform cannot distinguish between the right and left foot; therefore loading is assumed to be equally distributed through the legs. The accuracy of this assumption will vary between techniques.

The motion analysis system has several limitations:

- Even with eight cameras, the close proximity of the volunteer to the bed and to the patient often produces physical interference that results in loss of video contact with markers. The ability to check this problem during data collection is critical for ensuring that complete data sets are collected.
- A large number of markers is required to capture whole-body kinematics. This results in very large data files and limits the duration of sampling to less than 50 seconds. Activities that require longer than 50 seconds to complete must be performed in several shorter segments.
- The digitizing system is easily confused by any metallic or reflective material within the camera field of view. All belts, watches, jewelry, reflective shoe markings or shiny aspects of the bed or overhead lift must be removed or covered.

The force matching protocol has several limitations:

- Inserting the force gauge between the patient and the volunteer influences the posture, grip strategy, and tactile feedback for the volunteer. This may influence the volunteer's ability to accurately estimate an equivalent hand force and excludes measurement of whole-body kinematics during use of the force gauge.
- Hand forces often change throughout the technique. The force gauge used in this study was not capable of recording dynamic hand forces; therefore, peak force or mean force must be used as input to the biomechanical model. Use of a load cell or pressure sensor with real-time recording would improve the fidelity of this technique.

Despite the limitations and challenges outlined above, significant progress was made in the development and integration of data collection and analysis methods that allowed for a comparison of top-to-bottom and bottom-to-top biomechanical modeling approaches, and that allowed for the evaluation of patient handling tasks involving both manual and mechanically assisted techniques.

Objective 2: Comparison of Biomechanical Modeling Approaches

The top-to-bottom approach involved input of hand-reaction forces (force matching) and propagation of moments through each body segment from the hands to the L5/S1 lumbar spine. This approach allows for estimation of shoulder moments and L5/S1 moments and loading. The bottom-to-top approach involved input of foot reaction forces (force platform) and propagation of moments from the feet to L5/S1. Because of an infinite number of solutions in propagating moments through the right and left shoulders, this approach is not practical for estimating shoulder moments. The force matching technique is commonly used because it allows for relatively easy estimation of reaction forces without the limitations of an expensive force platform, without limiting data collection to a laboratory environment, and because it also allows for an estimate of stress at the shoulder; however, force matching limits biomechanical analysis to a static or pseudo-dynamic model that considers only peak or mean hand-reaction forces. In the case of the PEAK motion analysis system, the static hand loads can be used as input to a model with dynamic kinematics, resulting in a pseudo-dynamic model. Force matching and static biomechanical models are best suited to field studies or to patient handling techniques that require foot movement beyond the area of a force platform.

The force platform technique provides continuous, dynamic input to the biomechanical model and is more sensitive to variation in force application during the activity. The force platform method has higher fidelity than the force matching approach and is preferable when a laboratory environment can be used to simulate a patient handling task where there is relatively little movement of the volunteer's feet.

A comparison of the lumbar loads estimated for patient repositioning tasks using both biomechanical methods is provided below.

Objective 3: Preliminary Analysis of Patient Repositioning Tasks

Estimation of Tissue Stress

The estimated reaction forces at the hands are summarized in Table 3, based on the peak force measured during force matching trials and segmental biomechanics that propagate from the hands towards the feet (top-to-bottom biomechanics). Hand-reaction forces for some activities were too low (<5 N) to measure using the force gauge. These activities were not included in subsequent calculations using top-to-bottom biomechanics.

Peak and mean shoulder moments estimated using the hand reaction forces from the force-matching protocol are summarized in Table 4. Shoulder moments cannot be reliably estimated when foot-reaction forces are used as inputs to a linked segment model, since the division of the spinal moments into shoulder moments is an indeterminate problem with an infinite number of solutions; therefore, shoulder moments are only reported for the top-down method.

Table 3. Estimated Reaction Forces at the Hands.

Repositioning Technique	**Peak Hand Force (N)**	
Manual (2 person slider sheet))	**Two Hands Net**	
Up in bed	98.7 ± 27.6	
Across bed	99.3 ± 24.0	
Mechanically assisted	**Right**	**Left**
Turning away	76.4 ± 22.1	13.8 ± 19.1
Turning towards	49.5 ± 8.6	4.8 ± 9.8
Hooking sling to overhead lift	<5	<5
Moving up or across the bed	<5	<5

Table 4. Net Shoulder Moments for Specific Patient Handling Task Components				
Repositioning Technique	**Peak Shoulder Moment (Nm)**		**Mean Shoulder Moment (Nm)**	
Manual (2 person)	**Right**	**Left**	**Right**	**Left**
Up in bed	48.4 ± 28.9	45.3 ± 30.2	20.8 ± 3.8	15.4 ± 3.7
Across bed	33.4 ± 8.9	58.7 ± 22.7	17.4 ± 7.8	20.0 ± 11.8
Mechanically assisted				
Turning away	69.0 ± 34.8	51.0 ± 13.4	17.0 ± 3.8	8.5 ± 0.9
Turning towards	41.9 ± 12.1	34.3 ± 17.6	13.2 ± 3.1	6.1 ± 1.9
Hooking sling to overhead lift	n/a	n/a	n/a	n/a
Moving up or across the bed	n/a	n/a	n/a	n/a

Peak and mean compressive and shear loads estimated using both hand reaction forces (top to bottom biomechanics) and foot reaction forces (bottom to top biomechanics) measured at the force platform are summarized in Table 5 and Table 6. The lumbar spine compressive loads that were estimated for all tasks and task components are well within the guidance of 3400 N recommended for occupational exposures (Waters et al., 1993) and lower than those reported by Daynard et al. (2001) and Zhuang et al. (1999) for similar repositioning tasks. The lower estimates of compressive loading found in the current study may be related to experimental procedures and quality control practices that encouraged all subjects to use optimal technique and body mechanics rather than allowing free technique.

Table 5. Lumbar Spine (L5/S1) Compressive Loads Estimated Using Foot-Reaction Forces (Bottom-up model) and Hand-Reaction Forces (Top-down model) for Specific Patient Handling Task Components (± 1 standard deviation)

Repositioning Technique	**Peak Compressive Load (N)**		**Mean Compressive Load (N)**	
Manual (2 person)	**Bottom-up**	**Top-down**	**Bottom-up**	**Top-down**
Up in bed	501 ± 96	341 ± 85	440 ± 56	325 ± 70
Across bed	490 ± 82	397 ± 62	479 ± 90	395 ± 62
Mechanically assisted				
Turning away	376 ± 68	355 ± 55	356 ± 76	342 ± 51
Turning towards	391 ± 35	355 ± 52	378 ± 37	347 ± 51
Hooking sling to overhead lift	437 ± 76	n/a	435 ± 76	n/a
Moving up the bed	457 ± 67	n/a	453 ± 68	n/a
Moving across the bed	474 ± 64	n/a	470 ± 65	n/a

Table 6. Lumbar Spine (L5/S1) Anterior-Posterior Shear Loads Estimated Using Foot-Reaction Forces (Bottom-up model) and Hand-Reaction Forces (Top-down model) for Specific Patient Handling Task Components (± 1 standard deviation)

Repositioning Technique	Peak Shear (N)		Mean Shear (N)	
Manual (2 person)	**Bottom-up**	**Top-down**	**Bottom-up**	**Top-down**
Up in bed	83 ± 30	179 ± 51	51 ± 34	154 ± 52
Across bed	372 ± 154	248 ± 131	202 ± 47	72 ± 75
Mechanically assisted				
Turning away	375 ± 71	263 ± 69	269 ± 71	197 ± 51
Turning towards	384 ± 100	282 ± 68	279 ± 74	176 ± 74
Hooking sling to overhead lift	307 ± 110	n/a	143 ± 37	n/a
Moving up the bed	272 ± 287	n/a	95 ± 33	n/a
Moving across the bed	246 ± 98	n/a	68 ± 22	n/a

Estimation of Cumulative Stress

Cumulative stress is a concept in which the tissue loading is considered to accumulate from sustained or repeated loading; therefore, cumulative stress is calculated as the integral of stress by time. The cumulative moments and loads associated with a single repetition of specific patient handling task components are summarized in Table 7. The complete technique of repositioning is comprised of several task components and may or may not require placement of a sling or a slider sheet beneath the patient (Table 8). Placement of a sling or slider sheet requires turning the patient away and toward the caregiver, which is not required if the sling or slider sheet is already in place.

Table 7. Duration and Cumulative Stress (Shoulder Moment, L5/S1 Compressive and Shear Loading) of Specific Patient Handling Task Components.

Repositioning Task	Dur (s)	Shoulder Moment (Nms)		L5/S1	
		Right	**Left**	**Comp (Ns)**	**Shear (Ns)**
Task components					
Turning away	3.3	230	170	1255	1251
Turning towards	3.0	1269	102	1160	1139
Hooking sling to overhead lift	10.3			4475	3147
Assisted up in bed	8.7			3963	2364
Assisted across bed	9.1			4330	2245
Manual up in bed	2.1	102	96	1060	175
Manual across bed	2.1	141	419	1042	792

Table 8. Duration and Cumulative Stress (L5/S1 Compressive and Shear Loading) of Complete Repositioning Tasks.

Repositioning Task	Dur (s)	L5/S1 Comp (Ns)	L5/S1 Shear (Ns)
Assisted, sling in place			
Up in bed	18.9	8438	5511
Across bed	19.4	8805	5392
Assisted, no sling in place			
Up in bed	25.2	10854	7902
Across bed	25.7	11221	7782
Manual, slider in place			
Up in bed	2.1	1060	175
Across bed	2.1	1042	792
Manual, no slider in place			
Up in bed	8.4	3475	2566
Across bed	8.4	3458	3182

Comparison of Lumbar Load Estimation Using Hand or Foot Reaction Forces

The loads at the L5/S1 lumbar spine were calculated using both reaction forces at the hand (force matching technique) and reaction forces at the foot (force platform) as input variables to a linked segment biomechanical model. Under the conditions of the current project, use of the force matching technique consistently resulted in smaller peak compressive loads at the lumbar spine by 6 to 32 percent, compared with those estimated through use of a force platform. These results were statistically significant for peak compressive loads during manual turning tasks (p=0.0009) and sliding tasks (p=0.012), and for mean compressive loads during sliding tasks (p=0.017). Mean compressive loads during turning tasks were not significantly different when estimated using hand or foot-reaction forces (p=0.21). Mean shear load estimates using hand-reaction forces were lower than those estimated using foot-reaction forces for manual turning tasks by an average of 33 percent (p=0004) and for repositioning tasks an average of 190 percent (p=0.000004). Peak shear load estimates for turning patients were 29 percent lower when estimated using hand-reaction forces than foot-reaction forces (p=0.0008); however, there was no significant difference between peak shear estimates for repositioning patients up or across the bed (p=0.85).

It is assumed that reaction forces measured using the force platform are more accurate than those estimated with the force matching technique, based on the direct measurement obtained from the force platform during the task of interest, compared with measurement of reaction forces at the hand during a simulation of the task of interest. Hence, the compressive and shear loads estimated through force matching are assumed to underestimate the more accurate loading estimated using the force platform.

Comparison of Manual and Assisted Repositioning Techniques

Higher peak loading and moments are believed to indicate a greater physical demand on the tissues and an increased probability of injury. The peak moments at the shoulder and peak. compressive loading estimated for manually repositioning a patient up or across the bed were not statistically different than those estimated for manually turning a patient, which is required for placement of a sling or slider sheet (p=0.17). However, shear was larger for manually turning a patient than for manually repositioning up or across the bed ($p=1.3 \times 10^{-7}$). These findings suggest that peak tissue loading is associated with turning the patient to place the sling or slider sheet, which is a requirement for both manual and assisted repositioning techniques.

The manual repositioning technique (using a repositioning sheet) was faster to execute than the mechanically assisted technique (using a ceiling lift). The longer duration of the mechanically assisted techniques resulted in greater cumulative stress than estimated for the manual techniques. The literature is not clear about whether instantaneous loading or cumulative loading present greater risk for injury; however, eliminating the requirement for turning patients in bed to place slings or slider sheets reduces exposure to both peak and cumulative loads for manual and assisted repositioning techniques and reduces the amount of time required to perform these activities. This suggests that a reduction in injury risk associated with repositioning patients could be realized from maintaining a sling or slider sheet beneath the patient as part of the regular activity of changing bed linens rather than placing the slider sheet or sling when patient repositioning is required.

In practical application, a separate sling is used for lifting/transferring a patient to or from the bed and for repositioning the patient within the bed. Pre-placement of a sling on the bed may not be practical if both types of slings are required for a single patient. The development of a sling that works equally well for both lifting/transferring and repositioning would support pre-placement of a sling on the bed and use of an overhead lift for both types of patient handling.

Implications for Future Research on Occupational Health

While there are several studies that have provided biomechanical analyses of manual patient handling methods, there are relatively few studies that have provided analyses for mechanically assisted patient handling, and fewer still that have performed comparisons of manual and mechanically assisted patient handling techniques. This research begins to fill an identified gap in the current scientific literature.

Further methods development is required to address the limitations and challenges that were identified for both biomechanical methods in the present study. Alternate technologies for more effectively measuring dynamic ground reaction forces and hand reaction forces, and methods of accounting for physical interaction between the caregiver and the bed would improve the robustness of these approaches and the range of activities that could be assessed. Additional analysis is also required to verify and validate the model outputs and to thoroughly understand the interaction of input variables that contribute to data variability. Expanding the pilot analysis of the present study to a larger sample size would allow for more detailed statistical analysis of results and may be able to more effectively distinguish between patient handling techniques.

There is a need to evaluate the specific recommendations in this report concerning preferred techniques for repositioning patients, both in terms of practicality within clinical practice and in terms of validating the results with a larger sample of subjects that will provide greater power in statistical analyses. In addition, it is necessary to situate the analysis within the larger context of organizational culture and promoting a safety climate in healthcare, as the benefits of one technique over another must consider the psychosocial aspects involved, not just the biomechanical factors. For example, psychological factors are known to influence mechanical loading on the body through changes in posture, movement and exerted forces (Daraiseh et al., 2003), and thus the way in which decisions regarding preferred techniques are made can have a powerful effect on the outcome achieved. The techniques evaluated in the present research were performed under controlled, ideal conditions that supported the use of preferred postures and techniques.

The development activities in this project provide the foundation for future research to establish and validate a biomechanically and physiologically valid approach to quantifying the risk of injury to health care workers, based on knowledge of their work activities. This is not currently possible because of the lack of an integrated database or approach that estimates biomechanical loading for the complete range of patient handling activities that are utilized in the workplace. Further research is required to refine and to apply the analysis methods that were developed during this project to a systematic analysis of both commonly used and controversial patient handling techniques. This approach holds the potential for quantitative risk assessment towards the development of evidence-based patient handling best practices. Research that specifically examines the epidemiological link between biomechanical estimates of tissue stress (e.g., cumulative compressive and shear loading of the lumbar spine), patient handling practices, and injury rates in care givers would provide additional information that could be used to quantify and predict injury rates from an analysis of existing or proposed patient handling practices. In addition, further research is required to understand whether instantaneous loading or cumulative loading present a greater risk for injury. Further research is also required to understand the impact of psychosocial factors, such as organizational culture and safety climate, on the application of preferred techniques within clinical practice and on the resulting peak and cumulative tissue loading. This project has provided a method for estimating tissue stress during patient handling, which can provide an important contribution to the future research outlined above.

Policy and Prevention

Clear, evidence-based guidance for best practices is needed in the health care industry to help control both the financial and human cost of injuries associated with patient handling. The development of best practices that reflect the availability of mechanical assists for lifting, transferring and repositioning patients has been hindered by a lack of guiding scientific evidence, and a subsequent lack of consensus regarding best practices among health and safety leaders in the industry. The objective biomechanical method developed in this project to evaluate manual and mechanically assisted patient handling techniques will provide locally relevant scientific evidence that can guide decision making regarding best practices. The ready availability of this approach within a BC research facility allows for new techniques and applications to be evaluated on an ongoing basis, and will support the continued maintenance of best practices that reflect current knowledge and currently available equipment.

The knowledge gained from this project provides evidence to directly guide best practices for repositioning patients in bed, based on a comparative analysis of manual and mechanically assisted techniques. Maintaining a slider sheet or a sling beneath patients who are likely to require repositioning in bed will result in a reduction in both peak and cumulative tissue loading for the health care working performing the repositioning task. This information will be of use to Health and Safety professionals within the provincial health authorities and to facility-level stakeholders who are involved in the development and implementation of clinical practice guidelines. OHSAH is collaborating with the provincial health authorities, unions representing healthcare workers and with the WCB Prevention Division, Industry Services - Health Care group to facilitate the generation of provincially valid consensus guidance for patient handling.

Dissemination and Knowledge Transfer

OHSAH was honoured by the Canadian Institutes for Health Research with a Knowledge Translation Award, and is well positioned to ensure that the knowledge gained in this project is disseminated widely. The dissemination plan for this project includes multiple levels of approach that target the British Columbia health care community as well as the national and international community of health and safety professionals.

British Columbia Health Care Community

OHSAH utilizes a system of web-based and paper-based "Project Updates" to communicate research findings in a format that is easy to read and accessible to a variety of industry stakeholders. A Project Update will be distributed throughout the British Columbia health care community and will be available to others worldwide on the OHSAH website. OHSAH is also in a position within the British Columbia health care community to provide support to the regional health authorities in establishing best practices guidelines for patient handling.

National Health and Safety Professionals

The findings of this project will be presented at the 38th Annual Conference of the Association of Canadian Ergonomists, to be held October, 2006, in Banff. This conference brings together ergonomists and allied professionals from across the Canada.

Peer Reviewed Publication

A manuscript is in preparation for submission to the peer reviewed journal Applied Ergonomics. This journal is distributed worldwide.

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Appendix A – Patient Handling Technique Descriptions

Manual Patient Handling Technique

The specific manual technique using a repositioning sheet was determined from an informal survey of current practices in three British Columbia health authorities and two large healthcare facilities. The specific technique for manual repositioning up in bed involved the following considerations in the starting position:

- the bed was positioned in parallel with the long axis of the force platform;
- the bed elevation was adjusted so the upper surface of the mattress was at the height of the subject's upper trochanter (hip);
- the bed side rails were lowered out of the way;
- the repositioning sheet was in position beneath the patient and not tucked into the bed;
- the patient was positioned in the centre of the bed with arms crossed over the chest, chin tucked forwards toward the chest, and shoulders in line with the top of the repositioning sheet;
- the subject was on the right side of the bed, as viewed from the foot of the bed;
- the subject's feet were shoulder width apart and completely on the force platform;
- the subject's right foot was angled approximately 45 degrees towards the head of the bed (in the direction of intended movement);
- the subjects knees were slightly bent with the majority of weight on the left foot;
- the subject's lower body is not touching the bed;
- the subject's right shoulder (closest to head of the bed) was aligned with the patient's shoulders;
- the subject's arms were flexed at the elbow approximately 90 degrees, with palms up and the elbows touching the subject's torso; and
- the near edge of the repositioning sheet is rolled to provide a handle and the subject leans backwards slightly to make the sheet taut.

The repositioning up in bed was then completed with the subject calling a count to three and shifting weight from the left to the right foot on the 'three-count'. The subject moved the patient in a smooth motion until the upper edge of the repositioning sheet landed in the target zone indicated on the bed sheet.

The specific technique for manually repositioning the patient across the bed to the near edge was performed as per the technique for up in bed, with the following exceptions:

- the bed was placed perpendicular to the long axis of the force platform;
- the patient's legs were shifted approximately 20 cm towards the near side of the bed;
- the subject's feet were shoulder width apart and staggered so that one foot was in front of the other (both feet are on the force platform); and
- the subject's knees were slightly bent with the majority of weight on the front foot.

The repositioning to the side of the bed was performed by shifting weight from the front to the rear foot until the patient landed in the target zone indicated on the bed sheet.

Mechanically Assisted Patient Handling Technique

The use of an overhead lift for repositioning patients is a recommended alternative to manual repositioning techniques. The specific technique and body mechanics were based on training provided by a representative of the overhead lift vendor, and confirmed as a perceived best practice through consultation with individuals who train healthcare workers regionally. It was noted that the protocol in some facilities involved placing the sling on the bed as a component of the bedding for patients who required the use of an overhead lift, while the protocol in other facilities was to install the sling at the time of use. The protocol will vary across facilities and is dependent on the resident's needs and the availability of slings. The protocol used in this study demonstrates the worst case scenario in which the patient must first be manually repositioned to install the sling before they can be repositioned mechanically.

The PEAK data collection system used to capture kinematic data was limited in the amount of information that could be stored per data file. To accommodate the limitations of the data collection system and to allow for post-hoc analysis of repositioning without sling installation at the time of repositioning (i.e., sling installed with bedding), the mechanical repositioning task was broken down into the following five subtasks:

1. **Turn away**- turning the patient onto their side away from the caregiver to place the sling underneath;
2. **Turn towards**- turning the patient onto their other side toward the caregiver to complete positioning of the sling beneath the patient;
3. **Attach sling**- attaching the sling loops to the ceiling lift hooks;
4. **Raise and reposition**- raising the patient using the ceiling lift control and moving the patient either up in bed or to the side of the bed;
5. **Lower and unsling**- lowering the subject back onto bed using the ceiling lift control and removing the sling loops from the ceiling lift hooks.

The specific techniques for each of the sub-tasks using the mechanical lift were as follow:

Sub Task 1: Turn away

1. the patient was prepared with the force-match apparatus
2. the bed elevation was adjusted so the upper surface of the mattress was at the height of the subject's upper trochanter (hip)
3. the pillow was placed against the side rail to act as cushioning
4. the side rail on the right of the subject was raised to act as a safety feature;
5. the bed was placed perpendicular to the long axis of the force platform;
6. the patient was positioned in the center of the bed, arms crossed over chest, with their left leg bent at 90 degrees
7. the subject was on the right side of the bed, as viewed from the foot of the bed;
8. the subject's hands were positioned at the patient's left hip or left knee (which ever was most comfortable for the subject) and shoulders
9. the subject was standing on top of the force platform with their feet shoulder width apart, with one foot staggered in front of the other;
10. the subjects knees were slightly bent with the majority of weight on their back foot;
11. the assistant was situated directly opposite to the subject on the other side of the bed in preparation to hold the patient once turned over;

The force-matching apparatus was prepared first to avoid assembling and disassembling between repeated trials. Turning the patient away was completed with the subject calling a count to three and then shifting their weight from the back foot to the front foot on the "three-count", demonstrating a pushing motion. The subject moved the patient in a smooth motion until the patient was on their side and secured by the assistant. The subject then positioned the sling under the patient and once correctly placed the patient was eased back into the lying position.

Sub Task 2: Turn towards
The technique used to turn the patient towards were similar to that in turning away with the main difference in that the weight shift was transferred from front to back foot. There were other differences in the start position between turn away and toward towards which include the following:

1. the patient was positioned in the center of the bed, arms crossed over chest, but with their *right* leg bent at 90 degrees;
2. the subject's hands were positioned at the patient's right hip or right knee (which ever was most comfortable for the subject) and right shoulder;
3. majority of the subject's weight was initially on the front foot.

Turning the patient towards was completed with the subject calling a count to three and then shifting their weight from the front foot to the back foot on the "three-count", demonstrating a pulling motion. The subject moved the patient in a smooth motion until the patient was on their side and secured by the subject. The assistant then re-adjusted the sling under the patient and once adjusted correctly the patient was eased back into the lying position.

Sub Task 3: Attach sling
The sling used with the ceiling lift was a standard 10 strap sling. Before slinging, a pillow was placed under the head of the patient and the carry bar of the lift was lowered to the subject's elbow height. The subject attached the 5 straps closest to them, 3 straps to support the upper body and 2 straps for the lower. The assistant attached the straps on the opposite side.

Sub Task 4: Raise and reposition
Raising the patient of the bed was performed by the assistant using the control panel of the lift. Once raised, the subject grabbed the straps second from the end of either side to reposition. The subject moved the patient in a smooth motion until the shoulders of the patient hovered above the target zone indicated on the bed sheet (either up in bed or across bed).

Sub Task 5: Lower and unsling
The assistant lowered the patient using the control panel of the lift once the subject has confirmed the target zone has been reached. Once lowered, the subject detached the 5 straps they had attached. The assistant detached the straps on the opposite side.

The first two sub-tasks were trialed first independently because the loading levels were predicted to be greatest at these points of task. Each of these sub tasks were conducted 3 times with a force-matching task simulation performed immediately following each successful trial to estimate hand reaction forces. Following the completion of the 2 subtasks, the complete task (all 5 sub tasks) was performed to measure the entire duration of the task. The complete task was then performed for another 3 additional trials to collect kinematic data. The data collection system used to capture kinematic data was limited in amount of information that can be stored. Thus the mechanical reposition task was broken down into the 5 subtasks to accommodate the collection methods. Ground reaction forces and force simulation for hand reaction forces were only collected for that of subtask 1 and subtask 2. Hand reaction forces were deemed negligible for subtasks 3 to 5 and were not measured.

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