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Digital Human Modeling of Caretakers Preparing Patients for Patient Transfer Devices

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Abstract: The rising prevalence of work-related musculoskeletal disorders (MSDs) among healthcare professionals and practitioners is alarming. Patient handling is the most prevalent cause of these cases. Despite new technologies being available to nursing personnel, such as patient lifting devices, manual handling of patients are still required for certain tasks such as applying a sling onto immobile patients. Also, there is a lack of proper handling techniques when doing such tasks. Traditional ergonomic risk assessment approaches in these environment present challenges, such as lack of resources, limited access to the population sample, and time constraints. This project aims to use the Jack™ digital human modeling software to model and assess ergonomic risks of a single caretaker transferring immobile patients onto a sling. Effects of different bed heights and handling methods (pushing and pulling) are explored to assess the spinal compression forces on the L5/S1 (lumbosacral joint). Results showed that higher bed height could have lower impact the joint, and that pushing the patient instead of pulling is preferred.

Keywords: Digital human modelling, patient transfer, Jack™, Task Analysis.

I. INTRODUCTION

In recent years, the number of musculoskeletal disorder (MSD) related injuries in the health care industry has seen a significant increase. Nursing, in particular, is one field that has shown high reported number of injuries due to MSDs, with studies showing incident rate of injuries within this profession seven times greater than the average among other industries [1]. Among all the reported injuries, patient handling was involved in 98% of these [2]. This hasbeen attributed to the rising number of elderly people needing assistance, as well as increased obesity among the population that requires care.

Various patient lifting devices currently available on the market have been shown to reduce injury risks among emergency medical and hospital care personnel who are required to lift and transfer patients [3]. Although such devices eliminate the need for manually transferring patients, caretakers still have to manually maneuver patients to apply and take off the sling. Such procedure requires caretakers to pull, push and lift the patient, leading to possible overexertion of the musculoskeletal system, as well as increasing the risk of slipping.

A thorough literature search and assessment of instructional guides of patient slights have shown that there is a lack of standard or recommended handling techniques associated with the application of a sling onto the patient. Without proper guidelines, the nursingstaffis exposed to hazardous situations, and we lack the information about the severity of the spinal forces that are acting during patient transfer assistance. Traditional research methods are time-consuming and are somewhat ineffective at quantifying the associated risks. Further studies on the effects of different heights during the lifting and pushing motions can be time-consuming and restrained by resources and manpower. Human digital modeling has been used successfully as an alternative to traditional research methods in recent years, which produced research findings that could potentially help reduce operating costs and compensation claims due to occupational injuries.

Such simulation software eliminates the aforementioned difficulties, due to being able to recreate both the environment and humans and their interactions with object. Using task analysis tools, these software packages are able to assess human performance and injury risks. The purpose of this study is to create a digital simulation of a caretaker handling and positioning an immobile patient to prepare them for application of a patient transfer sling, which will assess different factors of multiple scenarios (i.e. different bed heights, pulling, pushing.) in order to give us better insight on proper methods or motions that can minimize the risk of injury and/or lead to improved productivity and user experience. Additionally, it will provide insight into quantifying the risk associated during performing patient transfer tasks.

II. LITERATURE REVIEW

In recent years, MSDs have become of the leading and most expensive occupational hazards in the United Sates. Tasks such as patient handling (lifting, transferring, and repositioning) involve repetitive motions and often overexertion, which over time lead to MSDs [4]. Nursing practitioners, in particular,are frequently exposed to such injury risks. Despite the safe lifting limit of 50 pounds for 75% of the female workforce, an average nurse lifts an excess of one ton per shift [11]. In addition, when positioning a patient onto a sling, the required

pulling force could be as high as 75% of patient's body weight [12].
In 2011, MSDs accounted for 33% of all worker injury and illness cases reported [2]. In general, 67% of those result from overexertion to the back [10]. Much progress needs to be donein order to minimize the risk of MSDs, specifically relating to standardizing patient handling techniques and quantifying the risk associated with those [15]. Studies have shown that during the pulling motions at sub-waist heights, the weight of the object to be pulled and height of the pulling motion are significant factors on trunk kinematics [22].

Jack™ and other digital human modeling software have been used in the past due to their ability to emulate anthropometrically and biomechanically accurate human models in a simulated virtual work environment for ergonomic assessment purposes. Gill and Ruddle[5] used JackTMin a case study to show that the software is applicable and effective in various manufacturing domains. Ben-Gal and Bukchin[6] used a digital human model and its available assessment tools to optimize the dimensions of a packing station using a conveyer belt. Samson [9] believes that use of these software packages may shed new light on the importance of ergonomics in the healthcare sector by utilizing increased productivity, work satisfaction and reducing the injury risk by fitting the task to the human using proper patient handling equipment and workplace.
The software has been used in several healthcare related study involving ergonomics. Cao [7] utilized Jack™ capabilities to perform an ergonomic evaluation of sonography working postures which may cause short and long-term stresses or occupational injuries. This allowed Cao to obtain quantitative results that are difficult to achieve via traditional ergonomic assessment methods. Furthermore, Irshaidat [8] performed digital human modeling assessment on patient lifting via commercially available assistive devices such as roller-boards and inflated mattresses, showing us that non-standard hardware can also be modeled and emulated in Jack™'s virtual environment.

However, in all of these simulations, humans are interacting with inanimate objects (non-humans). Jack™ lacks the capability to handle human-to-human interaction, and previous research where the software has been usedhave not attempted to do so.

III.METHODOLOGY

A. Jack™ Software
The Jack™ digital human modeling software package will be used to assess low back injury risks for a single caregiver on various scenarios during the preparation of an immobile patient for the application of the sling onto the patients. Data were collected from instructional manuals and video footage to facilitate the task analysis with regard to the different motions the caregiver uses to prepare the patient for the application of the sling [18, 19, and 20]. Results from the task analysis were then used to build the digital environment that replicate the scenarios. This environment was populated with three elements: (1) the caregiver, (2) the patient, and (3) the bed the patient lies upon. The caregiver was represented by a female model at 50^{th}-percentile height (US female population). Since JackTM software lacks the ability to model human-to-human interactions, we chose to simulate the human patient using rudimentary CAD objects such as boxes and/or cylinders (as shown in Figure 1) with their weights calculated and scaled from the following populations (percentiles are for body mass): 5^{th}-percentile female, 50^{th}-percentile female, 50^{th}-percentile male, and 95^{th}-percentile male based on the anthropometric data of the US population.The typical height of a hospital bed frame ranges anywhere between 15" to 22," with an average of 19" [16]. The task will be modeled using a low bed height of 23" (which includes an estimated mattress height), as well as a high bed height of 33".

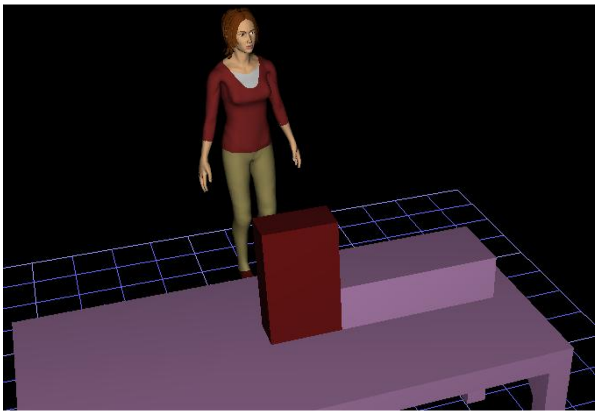

Fig. 1.Patient's body trunk and raised knee represented by CAD objects. Task Analysis

A task analysis of the entire activity a caretaker performs in order to attach the sling was performedin order to break down the procedure into most basic actions that will be modeled (Table 1). These actions were defined using Gilbreths' Therbligs, which are used in motion-time measurements (MTM) [23]. We use four therbligs in defining the activities as follows:

- Grasp – Closing fingers around an object in order to gain control of it.
- Reach – Motion of empty hand to or from object, usually preceded by Grasp.
- Position – Orienting the object so it is ready for future use, usuallyprepositioned to a predetermined location.
- Move – Movement of a loaded hand, typically with the purpose to release the object being handled at the end of motion.

When turning the patient onto their side, there are two possibilities: pushing the patient to the opposite side away from caretaker's body (Activities 2b and 6b), or pulling the patient towards the caretaker's body (Activity 2a and 6a). In case the patient bed is located alongside a wall, for example, both of these motions are necessary to properly

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position the patient, as it is impossible to pull the patient from the bedside next to the wall. In this study, we focus on tasks 1, 2a, and 2b.

TABLE I TASK ACTIVITIES

Activity		Type	Description
1		Reach, grasp and move knee	Elevate the patient's right knee until foot is flat on bed
2	a	Reach, grasp and move patient	Grasp patient's knee and right shoulder, and pull towards body in order to turn the patient sideways (patient's left side)
	b	Reach, grasp and move patient	Grasp patient's knee and right shoulder, and push away from caregiver's body in order to turn the patient sideways (patient's left side)

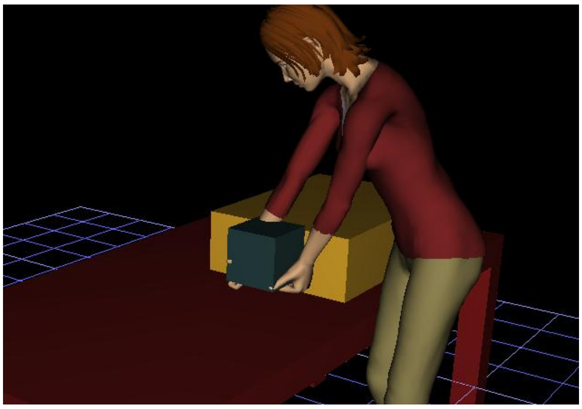

Fig.1. Caretaker lifting the knee to prepare the patient for turning to their side

In Figure 2 above, we demonstrate the simulation of Activity 1 in Jack^{TM}. The box represents the patient's knee, and we simulate the caretaker grasping the patient's leg just above the knee and lifting it until the patient's foot is approximately flat with bed. We estimate this distance to be around 18" in Jack^{TM}.Figure 3 shows Jack^{TM} simulation of the caretaker turning a patient to their side afterlifting their knee, either by pushing or pulling the trunk of the body and the raised knee.

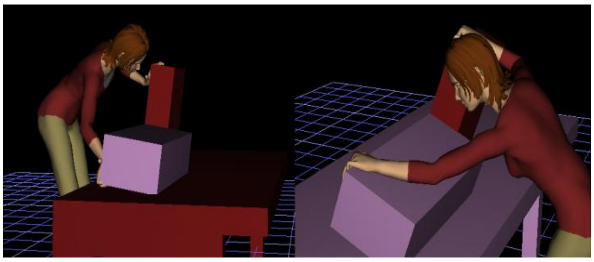

Fig. 3.Pushing the patient to their side (pictured left), and pulling the patient to their side (pictured right).

B. Model Assumptions

Using the anthropometric data of United States males and females [14], we were able to determine the patient weight for both male and female population (5th, 50th and 95th percentiles). However, we needed to account for biomechanical factors that impact the actual weight that's being handled. For instance, grasping a patient's knee and lifting it is not necessarily handling the entire weight of the leg, as the leg is actuallybeing supported by its foot on the bed and muscles and tendons have different impact on the force that's required to perform the movement. We estimate the weight being lifted when handling the knee is approximately equal to the weight of the upper leg of the patient, while the actual weighbeing handled when turning the patient sideways to be 30-40% of the total body weight. The weight of upper leg body segment was estimated using body segment proportion parameters [17]. These measurements are shown in Table 3:

TABLEIII BODY SEGMENTS WEIGHT IN KILOGRAMS

	Male		**Female**	
Percentile	**Body Weight (kg)**	**Upper Leg (kg)**	**Body Weight (kg)**	**Upper Leg (kg)**
5th	54.14	7.67	31.16	4.41
50th	82.1	11.63	69	9.77
95th	110.07	15.59	106.84	15.13

After each trial is modeled, we will create ergonomic reports which will assess the results. These tools include:

- Low Back Spinal Force Analysis (LBA) – estimates the spinal forces acting on virtual human's body over a course of time. These forces will be assessed against the NIOSH guidelines for compression limits in order toassess the severity of risk of injury.
- Static Strength Prediction (SSP) – this tool will estimate the percentage of male and female population that will be able to carry out each task.

Sample output of the data for LBA and SSP is shown in Appendix 2 and 3, respectively.

IV.RESULTS

After performing each simulation, maximum spinal compression forces (N) acting on L5/S1 during the period of activity were captured, which allows us to compare the different conditions.

A. Maximum Compression Force when Lifting the Knee

Looking at the data when handling the knee, we can see that higher bed height results in smaller compression force (Figure 4). This result was expected based on earlier research. All the values of maximum compression force are below the suggested design limit 3400 N set by NIOSH guidelines [21], making this task easily doable by a single caretaker.

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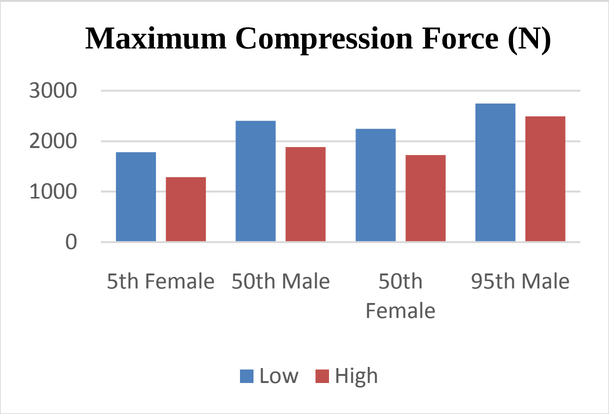

Fig. 4.Knee Handling Maximum Compression Forces

B. Maximum Compression Forces when Pulling and Pushing

The results for simulations involving turning the patient to their side (Figure 5) reveal several significant findings. In cases where the patient is a male falling under the 95th percentile of the population, the compression forces could be as high as 6860 N, which exceeds the maximum permissible limit of 6300 N set by NIOSH [21].

Furthermore, while height has similar impact to lifting the knee on compression forces, we can see that the method (pushing or pulling) may affect the spinal forces. At low bed heights, pushing and pulling show nearly identical results in the simulation. However, at higher bed height, pushing the patient produced much more favorable results. This implies that the method of handling the patient when the bed height is lower is irrelevant, but if pushing the patient is an available option to the caretaker (i.e. caretaker has access to that side of the bed) when the bed is raised, it should be used.

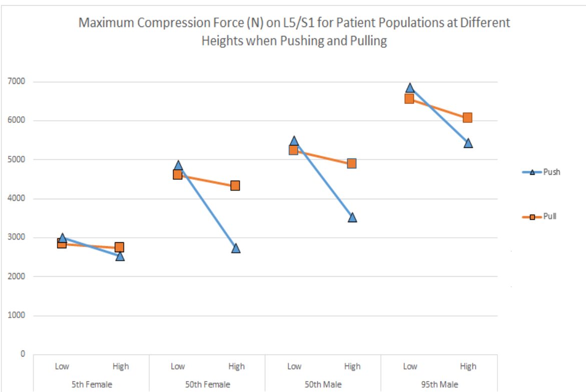

Fig 5.Maximum Compression Forces (N) on L5/S1 at different heights

The reason why pushing may be safer is explained by which muscle groups are acting during the two methods. When pushing the patient, the majority of the load is handled by the shoulders. In case of pulling the patient, additional bend is needed thus making the lower back muscle group act as an agonist during the task, adding additional compression force.

C. Static Strength Prediction on the Trunk

The 95th percentile male patient population poses a significant risk for back injuries. We can run the SSP tool to estimate the percentage of 50th percentile female nurse population that can actually perform this task. Since this study focuses on prevention of low back injuries, we only look at the trunk strength capability.

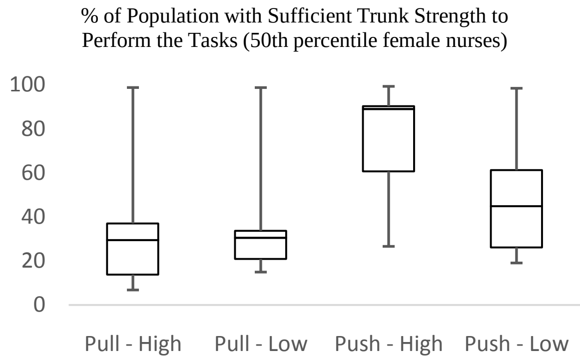

Fig. 6. SSP for pushing and pulling of patients at different bed height based on trunk strength

In case of pulling the patient at higher and lower bed heights, the percentage of population (which consists of nurses that fall in 50th percentile of female United State population) that is able to perform the task is as low as 6.73% and 14.86%, respectively. While pushing the patient does not improve this minimum significantly, there is a much higher spread where the population is able to perform the task. Again, we are seeing that higher bed height yields more preferable results, especially when pushing the patient.

Nonetheless, SSP results reveal to us that a significant portion of female nursing population is unable to position the patient properly when fitting the sling, due to lack of trunk strength to handle the load. A second or third person is needed to assist. Further research is needed to look at the difference in SSP when compared to male nursing population, as males tend to have higher upper body strength.

V. CONCLUSION

In this study, Jack™ simulation software was used to simulate human-to-human interaction between a caretaker and an immobile patient that require patient handling in order to attach a patient transfer sling. A task study was performedin order to determine the most common actions a caretaker performs when handling the patient. The tasks were carried out under various conditions: 23” and 33” bed heights, patient population consisting of 5th percentile female, 50th percentile male and female, and 95th percentile male based on United Stated anthropometric data, and performing certain tasks via different method (pushing and pulling). These activities were modeled in the software, and an ergonomic report was createdin order to assess the compression forces on the L5/S1 disk and an estimated percentage of population that could perform the task.

A. Recommendations

Using the Hazard Control Hierarchy [24] and the results of this study, we can make recommendations for equipment manufacturers and nursing staff training administrations.
The most effective ways to control the potential hazard is to eliminate the hazard or substitute a different equipment or procedure. There are new commercial products available in the markets that utilize friction-reducing surfaces in order to slide the sling under the patient, without the need to manually lift the patient. Usage of these products is recommended where applicable.

Proper administrative controls (training) are the next most efficient way in order to control the hazard. Based on the compression forces and static strength prediction results, patient handling should require a minimum of two caretaker to carry out. A small percentage of nursing population we looked at is actually unable to perform some of the tasks at all. Spinal compression forces on the L5/S1 disc could be as high as 6860 N, which can be classified as hazardous for the individual. Furthermore, if the hospital beds are height adjustable, we recommend raising the height to the maximum in order to further reduce the impact on the spine, while ensuring patient safety. Higher bed heights could lead to more severe injuries for the patients in case the patient is accidentally dropped. In addition, if the bed is raised to heights higher than standard hospital bed heights (up to 22”), we recommend the personnel use pushing motions when applicable. These recommendations cover the administrative (training) spectrum of the hazard control pyramid.

Using personal protection equipment (such as back braces) could also lower the risk of injury.

B. Importance

This project exemplifies methods to overcome limitations of computer software. Using various means (biomechanics and anthropometry) we are able to simulate a human-to-human interaction in Jack^{TM} software which doesn’t have that feature.

It also validates the findings relating to impact different heights may have on low back. Height has shown to have significant impact on center of pressure and trunk kinematics, and these results are an extension that confirm those results. Higher bed height exerted smaller compression forces on L5/S1 of caretakers.

As there is currently a lack of research that can help reduce MSDs in nursing, this study shows that hospitals need to implement strict guidelines when it comes to patient handling. Since the future technology (patient transfer devices) are also target for in-home use, proper training and warnings need to be issued to caretakers. Despite the fact that these devices are mostly designed to be used by a single person, the patient preparation and sling application should still be performed by at least two people.

C. Limitations and Future Work

The results in this study could be further verified and improved with modifications to the simulations. Currently, the human patients are represented by primitive blocks and forces needed to move the patient are estimated. Creating a proper CAD model of a human that includes proper joints and body segment weights would refine the results. Static Strength Prediction (SSP) tool used in the analysis is vulnerable to collision detection and jitter in animation. The data window employed in the result focused on the relevant time frame during the task, and potentially anomalous data points were excluded from the results.

Also, simulations involving different caretakers (males, various heights, etc.) may provide insight if and to what extent different anthropometry plays in compression forces.

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