Ergonomic Assessment of Patient Barrow Lifting Technique Using Digital Human Modeling

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Abstract. Healthcare personnel involved in patient handling activities are often exposed to work-related musculoskeletal disorders (WMSDs). Therefore, the objective of this study is to conduct a comprehensive assessment of the Barrow lifting technique using digital human modeling (DHM). This study investigates the effects of patient weight and height (PWH), clinical staff weight and height (CSWH), clinical staff position (CSP) during lift, and clinical staff gender (CSG) on the clinical staff's low back compression force (LBCF). In addition, the impact of specific postural variables was evaluated using Comfort Assessment (CA). The results of this research showed that clinical staff in the larger weight and height percentiles that are male experienced higher LBCF. While the trunk of the clinical staff member was exposed to higher flexion angles that are still in the comfort range, the ratings associated with the trunk thigh and elbow were outside the comfort range. The results of this research are of paramount importance in designing lifting protocols and training programs with the ultimate goal being a reduction in the risk of developing low back injuries.

Keywords: Patient Barrow Lifting, Digital Human Modeling, Ergonomics.

1 Introduction

Work-related musculoskeletal disorders (WMSDs) are injuries to the soft tissues of human body, such as muscles, tendons, ligaments, and nerves after repeated exposure to work activities. Several factors, including lifting task parameters, awkward posture, and repetition, are listed by the National Institute for Occupational Safety and Health (NIOSH) as risk factors associated with WMSDs [1]. WMSDs could lead to uncomfortable feelings and even injuries that need surgeries, or even a termination of careers. This study focuses on WMSDs in the healthcare industry.

Healthcare staff members are impacted by WMSDs due to their involvement in many activities that involve risk factors, such as manual patient lifting, awkward position during patient care, and long working hours. In fact, nursing personnel have one of the highest rates of WMSDs based on a study by the U.S. Bureau of Labor Statistics [2]. The risk of nursing personnel developing WMSDs have been increasing during the recent years. In 2002, nursing aids ranked second and registered nurses

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(RNs) ranked sixth in a list of at-risk occupations for strains and sprains [3]. In 2011, nursing aids ranked first and RNs ranked fifth, before construction workers who ranked seventh [2].

In addition to lost work time, a reduction in productivity, and possible career termination, WMSDs lead to an increase in the cost of medical care. In fact, about 12% of nurses leave the profession because of back injuries and 52% of them suffer from chronic back pain every year [4]. The facts that nurses leave their profession due to work-related injuries along with the shortage in this profession increase the workload for working nurses, making the working environment even more stressful.

Low back disorders (LBDs) have been found to be the most frequent WMSD, with an annual incident rate in the 30-60% range [5]. A variety of patient lifting tasks lead to LBDs [6]. For example, repeated patient lifting with outstretched arms and bent forward or even awkward postures could lead to injury. Preventive methods, such as lifting using devices, have been considered to assist nurses in those tasks, in an effort to reduce the risk of developing LBDs [7]. However, manual lifting is still widely used in healthcare facilities for various reasons, such as no adequate lifting devices and not enough awareness of safe or unsafe manual lifting [8].

Since nursing personnel are vulnerable to suffer from WMSDs, working posture analysis for patient lifting has been studied by many researchers. Traditional studies regarding patient lifting posture analysis are usually based on experimental studies using human subjects, which can be expensive and time-consuming. Therefore, this study chooses DHM to evaluate the ergonomics of the Barrow lifting technique, one the common manual patient lifting techniques. DHM helps address some of the limitations of traditional ergonomic assessment methods. The objective of this study is to analyze clinical staff's working posture during Barrow lifting. More specifically, this study evaluates the effect of patient characteristics (height and weight), clinical staff characteristics (gender, height and weight), and different positions and postures on lifting performance.

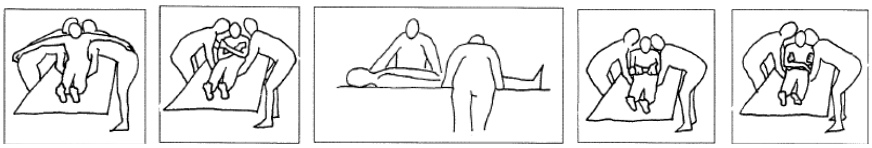
The remainder of this paper is organized as follows: Section 2 provides literature review about healthcare staff's working posture and patient lifting analyses. Section 3 illustrates the methodology used in this study. Section 4 presents the results and discussion. Finally, conclusions and future work are discussed in Section 5.

2 Literature Review

Most studies on patient lifting/handling were conducted using experimental methods or surveys [9]. The Ovako Working Posture Analysis System (OWAS) is one posture recording technique used in experimental studies. OWAS assigns a four-digit code to record the positions of various body segments. It can also reflect the level of risks. Hignett [10] adopted this system to evaluate nurses working postures for patient handling and non-patient handling tasks to record each observation by the position of the back, arms, legs, and estimated load. Statistical analysis was used to compare the results between patient handling tasks and non-patient handling tasks. The comparison showed that the percentage of risky working postures for patient handling

activities was much higher than those of non-patient handling activities. The potential limitation associated with the OWAS system is that the coding approaches could only give broad range rather than accurate information of postures [11]. Other types of posture recording systems have also been developed; however, most of these techniques are limited in their ability to provide precise evaluation of body posture and cannot effectively assess WMSDs risk factors, such as vibration and repetition.

With the development in observational techniques, postures can be recorded using videotape or computerized methods. Winkelmolen et al. [12] conducted a laboratory-based study to evaluate five manual lifting techniques by using a video recording system with the help of markers attached to several parts on the human body. The five manual lifting techniques were: Australian lift, Orthodox lift, Barrow lift, Through-arm lift, and Under-arm lift, as shown in Fig. 1. Ten female volunteers were involved in the experiments and another two volunteers with different weight were recruited as patients. Posture evaluation, compressive forces at the lower back, and perceived stress were used as evaluation indicators. More specifically, several indicators were used for posture evaluation, both at the beginning and end of the lifting, including back rotation and lateral flexion. While the results showed that patient weight did not lead to significant difference on posture evaluation, the five lifting techniques did have impact on the evaluation measures [12]. The Barrow lift was identified with the most significant compressive force and both Barrow and Orthodox lifts were observed with more subjective stress than the other techniques. Even though this study laid a good foundation for future study of manual lifting techniques, several limitations in recording and collecting data can be found, such as the difficulties in recording all motions with the videotaping system and missing values [12].



Australian lift Orthodox lift Barrow lift Through-arm lift Under-arm lift

Fig. 1. Five manual lifting techniques [12]

Freitag et al. [13] conducted a study to evaluate the stressful trunk postures of nurses by using computer-assisted recording and long-term analysis of musculoskeletal loads (CUELA) system, a computer-aided recording system. The system was attached to subjects with sensors on the joints to capture data about trunk and leg angles, as shown in Fig. 2. With the help of sensors, trunk movement can be assessed in 3D planes. The data was sent back to a computer that can re-construct the real body motions. The idea behind the ergonomic assessment was to investigate whether the joint positions deviated from neutral position severely. The higher the deviations from neutral position, the higher the risk of developing injuries.

Posture analysis can also be conducted using direct assessment methods, such as electric equipment that can output an electric signal related to human body's intersegmental displacement. The lumbar motion monitor (LMM), as an example of

electro-goniometer, is used to provide 3D information about trunk position, as well as its velocity and acceleration. Electromyography (EMG) is another widely used tool that can indicate the levels of muscle activity by generating various signal amplitudes for further analysis. For example, Marras et al. [6] used EMG-assisted model to assess the spinal loading for several patient lifting techniques (single person lifting vs. team lifting) by attaching bi-polar electrodes at muscles of interest. The LMM was also applied to collect instantaneous 3D data as shown in Fig. 2.

Fig. 2. CUELA measurement system, LMM and EMG systems in use [6], [13]

As stated earlier, there are several limitations for using experimental methods with human subjects, such as recruitment of subjects, workplace interruptions, the need for randomization, cost, convenience, etc. [14]. There is also the potential risk of exposing the subjects to risk or injury in experiments that involve lifting. Another approach for evaluating stresses on the human body or workload is survey analysis of self-reports, which can be in the form of rating scales through interviews or focused groups. Engels et al. [15] conducted a study to identify the risk factors associated with WMSDs for nurses using a questionnaire that was later analyzed using statistical analysis. The limitations of such methods include the subjective nature of the results, which may not be accurate or precise, as well as the lack of quantification of stresses caused by certain work postures.

In the past decade or so, digital human modeling has gained more interest in academia and industry [16-18]. Using virtual or computer-based environments, DHM allows for a wide range of applications including studies that involve crash simulations. In the healthcare domain, Samson [14] evaluated the ergonomics of patient lifting postures of paramedics using DHM. With the help of DHM, lower back stress was captured after analyzing different working postures while incorporating the anthropometric characteristics of paramedics and different lifting tools. Moreover, Salaskar [19] conducted an evaluation of laparoscopic surgery using DHM. The effects of laparoscopic monitor position, table height, and clinical staff's posture were measured using Rapid Upper Limb Assessment (RULA) score in the simulated environment. Finally, Cao [20] conducted a study to evaluate the sonography workplace and posture parameters using DHM. The sonography related work, such as typing and scanning were evaluated in an experimental design that includes percentile, gender, and posture using RULA, LBD and CA. In this research, the Barrow lifting technique is evaluated using digital human modeling.

3 Methodology

In this study, JACK 7.1 is used to develop a simulated model of the Barrow lifting technique. This research simulates the process in which two clinical staff members move one flat lying patient from a bed to another bed of the same height using Barrow lift. This technique requires the clinical staff to grasp each other's hand under the patient's waist [12]. More specifically, one person puts the other hand under patient's thighs, while the other person supports the patient's head by his/her free hand. The reason for choosing this lifting technique is because it involves asymmetric posture and load for the two clinical staff members. According to Winkelmolen et al. [12], the clinical staff member that lifts the lower part of the patient takes 60% of the patient's whole body weight, thereby experiencing higher loading than the person lifting the upper part of the body. The other person assumes the remaining 40% of the patient weight.

3.1 Experiment Design

The independent variables considered in this study are: percentile of PWH (5%, 50%, and 95%), percentile of CSWH (5%, 50%, and 95%), CSP (Head and Foot), and CSG (Male and Female). Therefore, there are 36 treatment combinations in this study. Throughout the study, a trunk flexion angle of 45° was maintained. Table 1 shows the combinations of all the experimental scenarios that have been simulated and tested in this research.

Table 1. Experimental combinations

Combination	*PWH/CSWH/CSP/CSG*	*Combination*	*PWH/CSWH/CSP/CSG*	*Combination*	*PWH/CSWH/CSP/CSG*
1	50th/5th/H/F	13	95th/95th/H/F	25	95th/50th/F/M
2	5th/50th/F/M	14	5th/50th/F/F	26	95th/50th/H/M
3	95th/5th/F/F	15	95th/95th/H/M	27	5th/50th/H/M
4	95th/50th/H/F	16	5th/95th/H/F	28	95th/50th/F/F
5	50th/95th/F/M	17	50th/95th/H/F	29	50th/50th/H/F
6	5th/50th/H/F	18	5th/5th/F/F	30	95th/95th/F/M
7	5th/5th/F/M	19	95th/95th/F/F	31	50th/5th/F/F
8	95th/5th/F/M	20	5th/95th/F/F	32	50th/5th/H/M
9	5th/95th/H/M	21	95th/5th/H/M	33	5th/5th/H/F
10	95th/5th/F/M	22	95th/5th/F/F	34	50th/50th/F/F
11	50th/50th/F/M	23	50th/50th/H/M	35	5th/5th/F/F
12	50th/95th/H/M	24	5th/95th/F/M	36	50th/5th/F/M

For each experimental scenario, data is collected on the L4/L5 force and comfort ratings for each person. For illustration purposes, Fig. 3 shows the simulated patient room, where two clinical staff members are lifting a patient from one bed to another using the Barrow lifting technique.

Fig. 3. Simulated environment in the Jack 7.1 software

3.2 Data Collection

The LBA and CA tools were used to evaluate the various treatment combinations, as shown in Fig. 4. LBA can measure the LBCF and compares the results with NOISH's compression action limits of 3400 N and maximum limits of 6400N. CA evaluates human posture parameters, limitations, and comfort ratings based on Porter's [21] database, which is already built in the Jack 7.1 software. In CA, green color indicates that the posture is located in the comfort zone and yellow color indicates that the posture located outside the comfort zone.

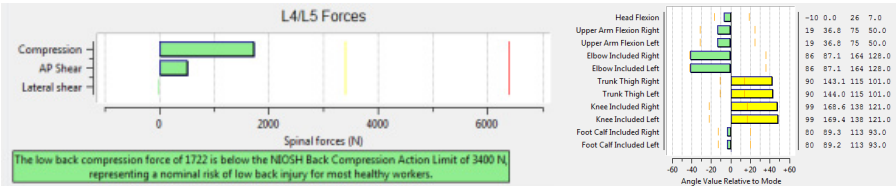


Fig. 4. LBA and CA analyses tools

4 Results

4.1 LBA

As shown in Fig. 5, out of the 36 combinations tested, only three have an LBCF that is lower than NIOSH's action limit of 3400N (safe region), indicating a nominal risk of low back injury for most healthy workers. A total of 31 combinations are above the 3400N action limit (but below the 6400N maximum limit), representing an increased risk of low back injury for some workers. The LBCF for the remaining two is above NIOSH's maximum limit of 6400N, representing an increased risk of low back injury for most workers, thereby requiring an immediate reengineering of the job.

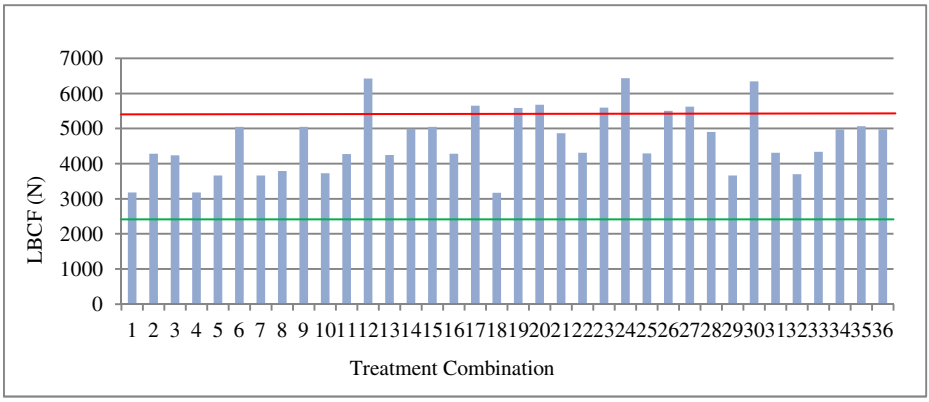


Fig. 5. LBCF analysis results

The ANOVA results in Table 2 show that the CSWH and CSG have significant impact on the LBCF at a 0.05 significance level. The results showed that the following interaction effects are significant: CSP*CSG, PWH*CSWH*CSP, and CSWH*CSP*CSG. The other interaction effects are not significant. As shown in Fig. 6, the LBCF increases when the percentile of CSWH increase. Fig. 6 also shows that males experience higher low back force than female clinical staff. However, the percentile of PWH and CSP do not have a significant effect on LBCF, which is consistent with the literature [12]. Furthermore, for a 95th percentile PWH, the head position clinical staff member experiences higher LBCF than the one at the foot position.

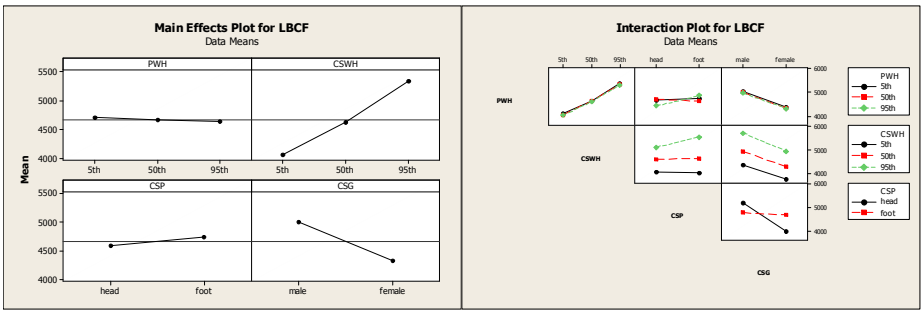


Fig. 6. Main and interaction effects plots for LBCF

Table 1. ANOVA results for LBCF

Source	*DF*	*Seq SS*	*Adj SS*	*Adj MS*	*F*	*P*
PWH	2	21484	21484	10742	0.07	0.935
CSWH	2	9918768	9918768	4959384	31.31	0.004
CSP	1	186480	186480	186480	1.18	0.339
CSG	1	3992670	3992670	3992670	25.21	0.007
PWH*CSWH	4	1637	1637	409	0	1
PWH*CSP	2	416321	416321	208161	1.31	0.364
PWH*CSG	2	2063	2063	1032	0.01	0.994
CSWH*CSP	2	387424	387424	193712	1.22	0.385
CSWH*CSG	2	53414	53414	26707	0.17	0.851
CSP*CSG	1	2798371	2798371	2798371	17.67	0.014
PWH*CSWH*CSP	4	7556981	7556981	1889245	11.93	0.017
PWH*CSWH*CSG	4	6262	6262	1566	0.01	1
PWH*CSP*CSG	2	264717	264717	132358	0.84	0.497
CSWH*CSP*CSG	2	2647028	2647028	1323514	8.36	0.037
Error	4	633586	633586	158397		
Total	35	28887207				

4.2 CA

The comfort rating depends on the output from major joints, including head flexion angle, head rotation angle, upper arm flexion, etc. In addition to the lower and upper bounds for the comfort rating, Jack 7.1 also provides the mode value, which represents the most comfortable angle. If the output is between the two limits, the posture is within the comfortable zone; if not, the posture is uncomfortable. The closer the output to the mode value for a specific joint, the more comfortable the posture associated with that posture. As shown in Fig. 7, the trunk thigh and knee are outside the comfort range. Fig. 7 also shows that the upper arm flexion and elbow included are in the comfort range. While the upper body experiences higher flexion angle that is near the comfort range's limit, the trunk thigh and elbow included are outside the comfort range.

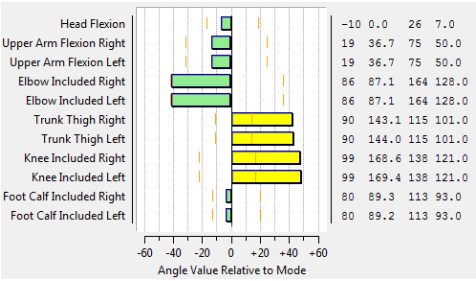


Fig. 7. Comfort ratings of 50th percentile male based on Porter's [21] database

5 Conclusions and Future Work

This study used DHM to assess the effect of percentile of CSWH, CSG, CSP during the lift, and the percentile of PWH when using the Barrow lifting technique. The impact of those variables on the LBCF on the L4/L5 of the clinical staff was investigated. With respect to position, there was no difference observed between the head and foot position clinical staff member, even though the person that lifts the patient's lower body experiences greater loading.

The results showed that the LBCF increases when the CSWH percentile increases. Also, male clinical staff members experience higher LBCF than females. The PWH percentile and the CSP have no significant impact on the LBCF. The head position clinical staff was observed to have slightly higher LBCF compared to that at the foot position. Even though three interaction effects were found to be significant, the interaction effect between CSP and CSG was the most visible (Fig. 6). Even though it remains in the comfort zone, the upper body of the clinical staff member experiences higher flexion angle. The trunk thigh and elbow included are outside the comfort range. Hence, keeping an appropriate distance between the clinical staff member and the patient bed, as well as avoiding significant bending of the upper body can keep the human body in the comfort zone.

Future work in this area will expand the modeling beyond having clinical staff members of the same percentile involved in the lifting process. In addition, since this study maintained a 45° trunk flexion angle, other angles can be considered in future studies. Furthermore, additional independent factors, such as patient body mass index, patient gender, and patient bed height can be considered in future research. Finally, the results of the Barrow lifting can be compared with other manual lifting techniques.

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