MEASURING BIOMECHANICAL LOADS ON THE SPINE DURING PATIENT LIFTING SLING APPLICATION AND REMOVAL: ASSESSING THE EFFECTS OF WORK METHOD, PATIENT WEIGHT AND BED HEIGHT

THESIS

Presented in Partial Fulfillment of the Requirements for the Degree, Master of Science, in the Graduate School of The Ohio State University

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The Ohio State University
2015

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Objective research is sparse on the biomechanics and ergonomics of the patient sling application and removal processes, which are necessary ancillary tasks that must be performed when using mechanical aids for patient transfer. This repeated measures study quantified the biomechanical loading on the spine as 12 female nurses applied and removed slings under two patients of differing weights (54 and 100 kg), using two work methods, and while working at three bed heights (56, 71, 93 cm). Three-dimensional spine loads at each vertebral level between T12/L1 and L5/S1 were measured using an EMG-assisted biomechanical model. Sling application and removal was performed either with the nurses remaining on one side of the bed for the entire task or by the nurse accessing the patient from both sides of the bed. Shear loading at the L5/S1 level and Lateral Shear loading at the L1/L2 level and above exceeded the tolerance threshold limit for disc failure. With respect to the lighter weight patient, the heavier patient led to significantly higher compression, A/P shear and lateral shear. While mean compressive forces were generally under 3400 N, several participants exceeded this level when applying the sling under the heavier patient. In general, working from both sides of the bed generated slightly higher A/P Shear loading than the one-sided method. Raising the
bed decreased compression and A/P shear significantly. Therefore, increasing the bed height to at least the nurse’s knuckle height is recommended based on the findings from this study.
DEDICATION

To my parents

and everything in this world that inspires my enthusiasm for art and science
ACKNOWLEDGEMENTS

I’d like to thank my advisor, Dr. Steven Lavender, for being a constant source of support and guidance throughout the length of this project. His optimism and energy have been great propellants for the completion of this project. I’m also extremely grateful to my co-advisor, Dr. William Marras for his consistent guidance. His penchant for the best quality in research has been a strong asset to this project. I’m also thankful to him for generously letting me use the facilities and resources of the Biodynamics Laboratory at the Ohio State University. Alongside me, this project has seen an equilateral sense of ownership from my research colleagues, Jaejin Hwang and Xueke Wang and my close friend, Kalyan Goparaju. Their commitment to this project, in time, effort and enthusiasm, has been invaluable. I’m also thankful to my research subjects who have taken time out of their busy schedules and eagerly participated in the several data collection sessions. This project has also seen very valuable contribution from research colleagues, Jonathan Dufour and Gregory Knapik and I’d like to thank them sincerely. Lastly, I’d like to thank my parents, my girlfriend and other friends and colleagues who have always been by my side, through the thick and thin.
VITA

Bachelor of Technology (Mechanical Engineering)…………………………….May 2011

FIELDS OF STUDY

MAJOR FIELD: INDUSTRIAL AND SYSTEMS ENGINEERING

SPECIALIZATION: HUMAN SYSTEMS INTEGRATION
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CHAPTER 1: LITERATURE REVIEW

1.1. Background:

Healthcare workers are known to have an increased prevalence and onset of work-related injuries and musculoskeletal disorders. This is particularly significant with workers in nursing occupations. According to the Bureau of Labor Statistics, nursing and residential care facilities recorded an incidence of 13.7 cases of non-fatal injuries and illnesses per 100 full time workers in 2013 (U.S. Department of Labor, 2013a). Specifically, nursing assistants recorded an incidence rate of 208.4 per 10,000 full time workers for non-fatal injuries requiring days away from work and work-related musculoskeletal disorders (U.S. Department of Labor, 2013b). This number was 55.7 for Registered Nurses. The median days away from work due to injury for these two occupational groups during the same period were seven and eight respectively.

The literature suggests that one of the critical work-related musculoskeletal disorders of concern for the nursing population is low back pain. Several epidemiological studies studied the incidence and prevalence of low back pain in nurses and estimated the impact of these on other systemic factors like lost work days or overall cost to the health care industry. Jensen, through a comparison of workers’ compensation claims, observed that nursing aides, licensed practical nurses, and registered nurses all had high back injury rates as compared to other occupations (Jensen, 1987). Pheasant and Stubbs (1992)
reported that the point prevalence of low back pain was 17 percent for nurses while it was 12.5 percent for the general population. The same study estimated a one year period prevalence of 43 percent for low back pain in nurses (Pheasant & Stubbs, 1992). They also highlighted that low back pain accounted for 16 percent of the sickness-related absence from work amongst nurses. In a longitudinal study of student nurses, Moffett et al. found that 64% of the nurses reported a case of low back pain during the 20-month follow up period of the study (Moffett et al., 1993).

A summary of several epidemiological studies also resonated with this concern of increased incidence and prevalence of low back pain in nurses (Hignett, 1996). Smedley et al. conducted a prospective cohort study over a two-year period that involved frequent follow-ups with subjects after every three months for estimating work related low back pain measures through self-administered questionnaires. The short time span for the follow-up ensured that the recall bias could be controlled and the researchers found that 38 percent of the subject population developed back pain during the follow-up period (Smedley et al., 1997). Eleven percent of the subject population considered for the prospective study had to take time off from work owing to low back pain. In another study, Smedley et al. looked at the sudden and gradual onset of low back pain for nurses at work. Again, the researchers observed that 38 percent of subjects reported a new episode of low back pain during the study period (Smedley et al., 2005). In a study of female nursing aides conducted in Taiwanese Nursing homes, the 12-month period prevalence of low back pain was found to be 66 percent. Nearly 11 percent of the nurses were found to have taken sick leave owing to back pain (Feng et al., 2007). Together,
these findings confirm that there is considerable risk of low back pain in the nursing population.

There is consistent evidence in literature that identifies certain occupational activities from the nursing profession as potential risk factors for the occurrence of low back pain. Epidemiological studies highlight manual patient handling as one of these key activities. Stubbs et al. (1983) conducted a retrospective study that surveyed a group of 3912 nurses. Seventy seven nurses per 1000 reported the onset of low back pain in the year preceding the survey and 29 of these nurses attributed the pain to patient handling activities (Stubbs et al., 1983). Other studies also identified patient handling as one of the key activities that are significantly associated with occupational low back pain (Harber et al., 1985). Pheasant and Stubbs reported that patient handling tasks were linked to significant incidence of back pain of acute onset in different types of nursing population (Pheasant & Stubbs, 1992). Eighty two percent of nurses who have reported back pain in a longitudinal study attributed at least one episode of back pain to a heavy lifting activity (Moffett et al., 1993). Hignett (1996) reported that frequent patient handling tasks appear to correlate with increased incidence of low back pain.

In a prospective study of nurses, Smedley et al. (2005) investigated the onset of gradual and sudden low back pain. The sudden onset of low back pain was found to be significantly greater in nurses whose work involved manual patient handling activities like transferring patients between a bed and a wheelchair or moving the patient in bed (Smedley et al., 2005). These findings complemented their earlier prospective study involving self-reported measures that associated low back pain onset cases with manual
transfer of patients between bed and a chair and patient repositioning tasks (Smedley et al., 1997). Feng et al. (2007), through logistic regression techniques for data from a cross sectional study, identified that manual transfer of patients was constantly associated with different measures of low back pain. Waters et al. (2007) suggested that the high risk tasks for nurses associated with the development of musculoskeletal disorders include lateral patient transfers, moving the patients to the head of a bed, or patient repositioning tasks in bed.

Supportive of these findings are the cumulative occupational injury figures published by the Bureau of Labor Statistics for 2013. The incidence rate for injuries occurring in nursing assistants due to over exertion experienced during lifting and lowering tasks was 49.6 per 10,000 full time workers (U.S. Department of Labor, 2013b). Further observation reveals that this rate is higher than that for all other injuries occurring for nursing assistants. Manual patient handling activities can be expected to involve overexertion in lifting and lowering and thus this statistic is a good representation of the significance of manual patient handling as a risk factor for the incidence of low back pain in nurses.

Ergonomics and biomechanics studies have attempted to shed further light on this subject by evaluating objective measures related to the spine of a nurse during the performance of manual patient handling activities. The advantage of considering the measures of ergonomics and biomechanics of the spine used in these studies is that they provide a valid understanding of the causal pathway through which manual patient handling activities might cause low back pain incidence in nurses.
A study that used the OWAKO posture analysis system concluded that 54 percent of the identified poor postures adopted by nurses during their work activities were associated with patient handling (Lee & Chiou, 1995). Hignett used the OWAKO analysis system to evaluate occupational nursing activities in 26 nurses and showed that the percentage of hazardous postures adopted by the nurses during patient handling activities was significantly higher than that found during non-patient handling activities (Hignett, 1996).

One study measured the spine compression forces at the L5/S1 joint during several manual patient lifting and transfer activities and found that the forces ranged between 3700 to 4900 N. This study used a static biomechanical model to estimate the forces at the L5/S1 joint (Garg et al., 1992). Another study using a similar biomechanical model evaluated several single person and two person patient handling tasks in a nursing setting that involved repositioning of patients in bed. The study concluded that the mean compressive forces ranged between 3315 N to 4487 N for the various methods tested (Winkelmolen et al., 1994). All these observed stress levels fall very close to, and in certain cases exceed, the 3400 N tolerance threshold limit for the initiation of vertebral end plate fractures (NIOSH, 1981). However, the forces estimated in these studies may have some underestimation to them. Both studies used joint angles as an input to the biomechanical model. Garg et al. (1992) approximated three dimensional body joint angles from a two-dimensional perspective seen from videos, which could be a source of error. In the latter study, the joint angles were measured at the starting point of the tasks involving exertion. However, there maybe a point during the performance of each task
when the postures could induce more critical joint angles, that might increase the L5/S1 joint loading.

Marras et al. (1999) evaluated several one-person and two-person patient handling techniques for transferring patients between a bed to a wheelchair or vice-versa, and the transfer of patients to and from commode chairs. The study also evaluated the repositioning of patients in bed using different one-person and two-person transfer techniques. Two risk evaluation techniques were used in the study. The first was the low back disorder risk model that considered parameters like lift-rate and spine kinematic variables to estimate the probability that the job would have an injury rate of 12 incidents per 200,000 hours of exposure (LBD risk model). The second method was the estimation of spine compression forces at the L5/S1 joint using a subject specific electromyographically-driven biomechanical model. The LBD risk model indicated that all the patient handling activities studied had applied forces and spine kinematics similar to those found in jobs with a back injury rate of 12 incidents per 200,000 hours of exposure. The biomechanical model also showed that all of the activities exceeded the 3400 N spine compression tolerance threshold limit for the initiation of endplate fractures and about 51 percent of the one-person transfer tasks exceeded the maximum threshold limit. The study also considered the Anterior-Posterior shear loads and the Lateral shear loads at the L5/S1 joint and found that these loads exceed the tolerance threshold value of 750N suggested by (McGill, 1997). This study concluded that any manual patient handling activity exposes caregivers to risk factors associated with the development of
low back pain and urged the use of mechanical assistive equipment for lifting, transferring or handling of patients (Marras et al., 1999).

Assistive equipment for patient handling have become more commonly used over the past several years in response to an increased awareness of the ergonomics of the patient handling process. Floor based or ceiling based lifting devices are used by caregivers when lifting and transferring patients between a bed and a wheelchair, or when repositioning patients in bed. These devices are mechanically, hydraulically or electrically assisted and can lift the patient who is in an appropriate sling. Thus, the assist device, rather than the nurse, bears the load during the patient transfer or handling activity. As is the case with ergonomic interventions, validation of the equipment is a necessity to estimate the actual improvement of the work activities in terms of ergonomics and biomechanics concerns.

Some research exists in this direction. One study compared the changes in the injury and lost workday rates before and after the implementation of mechanical assists in acute and long term care facilities. They found a significant decrease in the injury rates and lost days due to work injuries after the implementation of mechanical assists (Evanoff et al., 2003). Engst et al. (2005) evaluated a ceiling lift intervention introduced in a nursing facility with an alternate control group that involved manually handling patients. They found that in the intervention group, 71 percent of the nurses preferred to use the ceiling lift for the patient transfer activities and also found a significant reduction in the perceived risk of injury to the lower back which was measured through a questionnaire (Engst et al., 2005).
Some studies focused on the objective biomechanics measures of the spine for nurses using these lifts to perform patient transfer and handling activities. Biomechanics studies usually compare the spine forces measured during the use of lifts with the forces measured during manual patient lifting or with the tolerance threshold values for spine injury mentioned earlier. The latter is found to be a useful technique to evaluate whether different types of interventions will successfully address the high spine loads encountered in the patient handling process and adequately protect the targeted workforce. One crucial focus of research has been to compare the floor based and ceiling based lift devices and the evaluation of certain inherent design features of these devices.

Garg and Owen (1992) calculated the mean compressive force on the L5/S1 disc during several patient transfer activities before and after the implementation of a mechanical hoist. They observed a significant reduction of the forces from 4751 N to 1964 N by using a static biomechanical model (Garg & Owen, 1992). Garg et al. (1991) compared five manual transfer techniques with three techniques that used hoist type lift transfer systems during bed to wheelchair and wheelchair to bed patient transfer tasks. Some of the manual transfer techniques involved use of assistive devices like gait belt, walking belt and patient slings. The study used a 3D static biomechanical model to conclude that the lifting and pulling techniques that used the assistive devices produced less compressive force at the L5/S1 lumbar spinal joint (Garg et al., 1991). These studies primarily relied on a static biomechanical model for spine force estimations. However, the patient transfer activities being investigated involved a lot of dynamic activity, which has not been factored into the model. The postures for which joint angles were measured
to be used as inputs for the models were from the beginning of all the transfer tasks, which poses the same issue as described earlier. Similarly, Zhuang et al. (1999) used a 3D static biomechanical model to compare nine battery powered lifts to the traditional manual transferring technique alongside a sliding board and a waking belt type assistive device. They found that the basket sling, overhead lifts and the stand-up lifts resulted in less back compressive forces at the L5/S1 joint than the manual transfer technique during the transfer phase of the activity (Zhuang et al., 1999). Normalized mean and peak muscle activities, measured using surface EMG techniques, for the bilateral upper and lower erector spinae, latissimus dorsi and trapezius muscles were found to be progressively lower for floor based patient lifts and ceiling based patient lifts over manual patient transfers (Keir & MacDonell, 2004). Dutta et al. (2012) studied the differences in moments on the L5/S1 joint and the peak external hand forces during patient transfer tasks carried out by using a floor based and a ceiling based patient lift mechanisms. The ceiling based mechanism was found to generate considerably lower moments on the L5/S1 joint as compared to the floor based system (Dutta et al., 2012).

A more extensive comparison of the ergonomic advantage and the design features of ceiling based and floor based lifts was conducted by Marras et al. (2009). The study focused more on the patient transportation aspect of the patient transfer process as opposed to just the lifting part of this process, based on the understanding that the biomechanical concerns with respect to the actual lifting of the patient were alleviated with the lifting mechanisms shown used in the earlier research. Thus, several facets of the design of these lifts that contribute significantly to the transportation were compared. The
study used a 3D subject specific biologically assisted dynamic biomechanical model to estimate the A/P shear, lateral shear and compressive spine loads at all the lumbar vertebral endplate levels ranging from T12/L1 to L5/S1 based on surface electromyographic signals from 10 trunk muscles. The study observed that ceiling lifts reduced spine compression, A/P and lateral shear loads well below the tolerance limits when laterally shifting the lifted patients. However, the A/P shear loads with the floor lift were observed to be above the tolerance limits at the levels L3 and above. This was particularly exacerbated when the floor lifts had to be turned, irrespective of the degree of confinement. Thus, this study highlighted the advantage of using ceiling lifts over the floor lifts during the transportation part of the patient handling process.

Thus, literature suggests that the use of ceiling based mechanical assist devices, reduces the risk of spine injury through compression and shear loading of the spine when compared to manual patient handling.
1.2. Research Need:

Any intervention is not completely useful unless it has been proven to reduce the risk of injury when it has been used to replace the original process. Sometimes, the implementation of an intervention creates the need to perform ancillary tasks for the effective use of the intervention. One such key ancillary component of using mechanical assists like ceiling lifts for patient handling is the need to insert and remove lifting slings. A sling is usually a fabric product that wraps around and securely holds the patient during the lifting and transferring process. The sling has attachment points embedded into its design that allow it to be hooked onto the lift devices. Typically lifts have a spreader bar where the sling is attached to the hoist.

Patients need to be put on these slings before the actual lifting part of the transfer takes place. Depending on the particular transfer activity, the sling application task maybe done through different methods. The application of sling under a patient lying supine on a hospital bed involves a good amount of patient handling that has to be done manually. Similarly, the sling removal process, once the patient transfer process is complete, requires additional patient handling. Thus, the introduction of mechanical assistive devices for patient handling introduces a new set of manual patient handling activities that happen during the sling application and removal. Before one can conclude that the assist devices are effective at providing better conditions for patient handling,
there is need to evaluate the sling application and removal processes from an ergonomics and biomechanics standpoint.

Research is sparse on the ergonomics and biomechanics of the actual sling application process. Several sling manufacturers suggest a recommended technique to be used for the sling application and removal tasks (Ergolet America, 2011; Guldmann, 2013). This technique is designed to allow for suitable consideration of patient safety during the sling application as well as when the sling is actually put to use by hoisting it in the lift. This technique involves rolling of the patient lying supine on a bed, which entails to considerable pushing and pulling of the patient by the nurse. Further, depending on the design of the sling, the patient’s legs might need to be lifted to get supportive straps underneath them. There is a need to evaluate this process to verify if all these tasks are putting health care workers at an unforeseen risk of injury.

Gagnon et al. demonstrated that the task of turning a patient in bed generated L5/S1 compression forces up to 3526 N (Gagnon et al., 1987). Zhuang et al. (1999), in their comparison of several floor and ceiling lifts, considered the ‘patient preparation’ phase of the patient transfer process done using lifts. They considered the activities involving rolling the patient away and towards the nursing assistant. They used a 3D static biomechanical model to estimate the compression forces at the L5/S1 joint during these activities. The compression forces were found to be in the ranges of 2094 – 4367 N and 1804-4745 N for the ‘rolling towards’ and ‘rolling away’ activities (Zhuang et al., 1999). The peak forces thus estimated during these activities seem to be above the tolerance threshold limits for vertebral endplate fractures for both the studies. However,
the loading estimates from this study were obtained using a static biomechanical model, which does not capture the dynamic loading aspect of the task. Further, the study reported overall ranges of loading across the two patient conditions used. Thus, a more accurate estimation of compression loading for different patient weights is desired. Also, this study does not include estimation of compression loads at the upper lumbar levels and shear loads completely.

Santaguida et al. (2005) compared a selection of floor and overhead lifts during a patient transfer activity and estimated the A/P shear and compression loads at the L5/S1 joint. They divided the process of patient transfer from a bed to wheelchair into substituent phases and estimated the spine loads in every phase. The median compression and shear spine loads for phase one of the process, which was the sling application, were measured to be of the order of 1400 N and 250-300 N respectively (Santaguida et al., 2005). The study did not measure the loads during the sling removal process as it evaluated the lifts for only the bed to wheelchair patient transfer process. Further, the study measured the loads only at the L5/S1 joint. The study also considered the cumulative loading during the tasks performed, but the measure used for estimating cumulative loading may not be valid for comparison between two different tasks. As time period for task performance is difficult to control during, comparison of cumulative loading for the use of different designs of lifts may lead to over or underestimation of loads in some cases. Further, no set threshold exists for cumulative spine loading in the literature.
Further, observation of the sling application process as done by the recommended technique indicates that the process involves rolling of the patient on both the sides, which involves significant pushing and pulling. As demonstrated by Knapik and Marras (2009), pushing and pulling tasks generated A/P shear loads in the upper lumbar levels of the spine, which were higher than the tolerance threshold values. Thus, there is need to evaluate the sling application and removal process for loads at all the lumbar spine levels. This would provide a meaningful understanding of the actual biomechanical advantage of using ceiling based lifts as a replacement to manual patient transfer activities.
1.3. Biomechanical Model:

Extensive evaluation of biomechanical measures like the compression, A/P shear and lateral shear loading at all the lumbar vertebral disc endplate levels is necessary and quite useful as discussed earlier. Further, to investigate the ergonomics and biomechanics related concerns of any work process realistically and to evaluate the complete benefit of ergonomic interventions, the use of biomechanical loading models that are capable of evaluating free dynamic lifting in a three dimensional setup is imperative. Such a model has to be applicable to general population without any limitations related to the anthropometric or biological diversity associated with such a population. The Biodynamics Laboratory at The Ohio State University has been developing a subject-specific biologically-assisted 3D dynamic spine model that meets these criteria. The model’s development, capabilities and restrictions have been thoroughly described earlier (Marras & Sommerich, 1991; Mirka & Marras, 1993; Granata & Marras, 1993; 1995; Marras & Granata, 1995; 1997; Fathallah, 1997; Davis et al., 1998; Theado et al., 2007; Knapik & Marras, 2009; Dufour et al., 2013) and it shall only be briefly discussed here.

An overview of the functioning of the model is shown in Figure 1. This has been adapted from the model illustration shown by Knapik (2005). The model uses surface electromyography data, kinetic data, kinematic data and anthropometric data as inputs. In this model, the trunk muscles are considered as force vectors linked to the pelvis at the
lower end and the upper torso at the upper end. As the pelvis and upper torso move with
dynamic task performance, these force vectors are free to move along, thus changing
their behavior and force responses.

Figure 1: Overview of the EMG-Assisted Biomechanical Model developed by the Ohio
State University Biodynamics Laboratory

The model is validated by measuring the normalized Average Absolute Error
(AAE) between the moments predicted by the model and the moments measured through
captured task kinetics. Another correlation coefficient, $R^2$, is measured for the predicted and measured moments. The $R^2$ value has to be above 85% and the normalized AAE value has to be less than 0.1 for satisfactory validity of the model.

This model of spine provides a means for exploring the spine biomechanics of a task like the patient transfer sling application and removal, a task that potentially requires pushing, pulling and lifting exertions and three dimensional spine motions. Specifically, the model outputs include peak compression, A/P shear and lateral shear loads at all the different lumbar vertebral levels.
1.4. Ergonomics considerations:

It is imperative to evaluate the sling application and removal tasks in terms of several ergonomic considerations. Key task parameters that are hypothesized to affect the spine loading include the height of the bed upon which a patient is lying supine, the patient’s weight, the sling application method, the design of the sling, the number of caregivers at work, and the level of assistance provided by the patient. Literature exists on the consideration of the impact of these various factors in exclusivity and also in conjunction with various healthcare activities, and to some extent, patient handling activities. However, literature is sparse on the consideration of these factors in conjunction with the sling application and removal activities.

1.4.1 Bed Height:

Significant research exists on matching workstation design to the worker anthropometry and the subsequent ergonomic advantages. Changing the bed height to suit caregiver anthropometry has been studied in the context of manual patient handling. De Looze et al. (1994) studied the compression and shear forces at the L5/S1 joint for manual patient handling tasks conducted at a fixed bed height and an adjustable bed height. The height was adjusted to a condition chosen by the participant caregivers. The researchers observed lower values of compression and shear forces at the adjusted bed
height level (De Looze et al., 1994). Botha and Bridger conducted a study of anthropometric variability and workstation usability in a group of nurses and self-reported measures indicated that non-height adjustable beds were perceived to be too high for their daily activities by the nurses (Botha & Bridger, 1998). Another study reported a reduction in the time-integrated torque on the spine during an individually chosen bed height condition for nurses as opposed to a standard bed height condition for patient handling tasks (De Looze et al., 1998). Caboor et al. (2000) evaluated the spine kinematics and ‘range of motion’ variations of the spine when nurses used beds at a standard height and a second height level adjusted to a choice of their own. They reported that the frequency of motions in the ‘safe zone’ near the erect position increased significantly in the case with the adjusted bed height (Caboor et al., 2000).

This indicates a trend in research that highlights the advantage of adjusting the bed height for patient handling activities. The inherent need for an extensive analysis of the shear and compression loads on all the lumbar levels of the spine also exists for adjustable bed height conditions. Further, there is a need to evaluate the variability in bed height in an attempt to standardize certain height levels, which could offer the best ergonomic advantage to the nurses. Though it might be impractical to suggest a range of heights for the bed owing to numerous permutations of bed designs and hospital use conditions, suggestions made relative to anthropometric landmarks might be useful from an adoptability perspective. This also has the benefit of being applicable to a large population of nurses with significant variability in anthropometry.
1.4.2 Patient Weight:

Previous studies have reported the sensitivity of spine loads to patient weight during patient handling tasks. One study observed that by increasing the patient weight from the 25th percentile to the 90th percentile, the compression forces on the L5/S1 joint for the nurses increased by 903 N to 1545 N across various handling tasks like moving patients between beds, wheelchairs and toilets (Garg et al., 1992). Marras et al. (2009) showed that the shear loads in the spine during the pushing and pulling tasks related to the transport phase of the patient handling increased with an increase in the patient weight (Marras et al., 2009). However, there is no literature addressing the variability in spine loading due to variances in patient weight conditions during sling application and removal activities.

1.4.3 Sling Application Techniques:

Techniques for sling application as recommended by manufacturers generally involve a one-person or two-person process for the nurses depending on factors relevant to the exertion levels in the activity like the patient weight and the level of co-operation provided by the patient. Other systemic factors might also come into play, such as the staffing levels, which may vary over the course of the 24-hour day.

Marras et al. (1999) investigated the spine loads in nurses performing a selection of patient transfer activities manually. These activities were investigated both in a one-person and a two-person setting. The study concluded that all the manual patient transfer activities posed significant risk for low back disorder and generated spine loads in excess
of the tolerance threshold limits, particularly more for the case of the one-person transfer activities. The researchers also reported that for low back disorder risk, the actual task was less of a concern than the number of people performing the transfer (Marras et al., 1999). Thus, it is imperative to study the spine loads of nurses during one-person sling application and removal activities to establish the effectiveness of the patient lifts in minimizing spinal injury risk.

1.4.4 Level of Patient Assistance:

Another significant factor that goes hand in hand with the number of people performing the transfer is the level of assistance that the patient can provide during the preparation and transfer. For this factor also, there is a need to investigate the worst-case scenario in terms of the patient’s level of cooperation to investigate the maximum spine loading conditions for the nurses. This is resonant with earlier studies investigating manual and intervention based patient handling activities. De Looze et al. instructed patients to neither cooperate with the nurses nor work against the nurse in their study of manual patient transfer activities (De Looze et al., 1994). Marras et al. (1999) used a similar strategy in their study investigating one-person and two-person manual patient transfer activities. The patient was instructed to maintain a standard level of dependency, that is to maintain total dependency on the nurse and be non-weight bearing, but also be capable of following instructions and provide arm support (Marras et al., 1999). Another study involved investigation of patient transfer activities whilst the patient was instructed to remain passive (Hye-Knudsen et al., 2004). Contrary to this trend, Schibye et al.
(2003) allowed the patients’ assistance to the nurses when evaluating different patient handling tasks. The study was conducted in two phases, with the patient being instructed to remain passive in one phase, yet cooperate if the healthcare worker asked for it, and to help as much as possible in the second phase. However, it can be estimated that there is more activity, focus and need for care involved on the part of the nurses in the case when the patient is completely passive. Both the studies that considered spine loads during sling placement instructed the patient volunteers to remain passive during the sling application tasks (Zhuang et al., 1999; Santaguida et al., 2005). The current study also provides an opportunity to estimate spine loads during the sling application in this particular scenario.

1.4.5. Sling Application and Removal Method:

The basic sling application process can be split into five tasks –

a) Rolling the patient away from the nurse – which involves a pushing task for the nurse

b) Spreading a rolled up sling on the bed

c) Rolling the patient towards the nurse – which involves a pulling task for the nurse

d) Unrolling and spreading out the sling totally under the patient

e) Rolling the patient back onto the sling in a supine position.

The nurse essentially performs these tasks while standing on one side of the bed. Here, there is a potential for the nurse to walk over to the other side of the bed to perform the
third and fourth tasks. This would entail to the nurse performing two pushing tasks to
apply the sling instead of performing a pushing and pulling task.

Zhuang et al. (1999) demonstrated slightly lesser compression forces on the L5/S1 joint of the nurses while performing the ‘rolling away’ task than the task involving rolling the patient towards the nurse. The researchers commented that the ‘rolling away’ task brings the arms of the nurse closer to the body thus reducing hand force moments (Zhuang et al., 1999). The ‘rolling towards’ task has the arms of the nurse positioned away from the body thus possibly inducing spine flexion and a larger moment on the L5/S1 joint from the hand forces. Thus, this poses a question of whether it is better to have the nurse stand only on one side of the bed and use a pushing and pulling action during the sling application and removal, or it is better for the nurse to move around the bed and use only pushing actions to roll the patient.

Thus, this study provides an opportunity to investigate the sling application and removal process in a one-person activity with a passive patient, by measuring the spine loads at multiple lumbar vertebral levels. There is further scope with this study to consider the effects of patient weight, bed height and work method on these loads.
CHAPTER 2: STUDY MANUSCRIPT

2.1. Introduction:

2.1.1 Background:

Nursing personnel are known to have an increased prevalence and onset of work-related musculoskeletal disorders. One of the major concerns for this working population is low back pain. Researchers have reported the extent of low back pain prevalence and onset in nursing personnel (Jensen, 1987; Pheasant & Stubbs, 1992; Moffett et al., 1993; Hignett, 1996; Smedley et al., 1997; Smedley et al., 2005; Feng et al., 2007). The onset of low back pain in nurses was estimated to be around 38 percent through longitudinal studies (Smedley et al., 1997; 2005). The point prevalence of low back pain was reported as 17 percent by Pheasant & Stubbs (1992) and the 12 month prevalence was reported to be around 43 – 66 percent by several studies (Pheasant & Stubbs, 1992; Feng et al., 2007). Epidemiological studies have identified manual patient handling as one of the key risk factors associated with the onset of low back pain in nurses (Stubbs et al., 1983; Harber et al., 1985; Pheasant & Stubbs, 1992; Moffett et al., 1993; Hignett, 1996; Smedley et al., 1997; Smedley et al., 2005; Feng et al., 2007; Waters et al., 2007). Manual transfer of patients between beds and chairs was identified to be of key concern by these studies (Smedley et al., 1997; Smedley et al., 2005; Feng et al., 2007; Waters et al., 2007). Biomechanics studies looked into the loading on the L5/S1 joint of the lumbar
spine during the performance of several manual patient handling activities and documented the generation of loads in excess of the NIOSH recommended tolerance threshold limit for the initiation of vertebral endplate fractures (NIOSH, 1981; Garg et al., 1992; Winkelmolen et al., 1994). Marras et al. (1999) studied several one person and two person manual patient handling activities and reported that all the manual patient handling activities put nurses at high risk for low back disorders. The study also reported that the compression, anterior-posterior shear and lateral shear loading on the L5/S1 joint are all higher than respective tolerance threshold limits suggested (McGill, 1997; Marras et al., 1999). This study strongly recommended the use of mechanical lifting aids for the performance of patient handling activities.

The hoists used for lifting, transferring, and repositioning patients can be floor-based or ceiling mounted. Patients are lifted in a sling, which is attached to the hoist. These assistive devices have been shown to reduce the loads generated at L5/S1 joint relative to those experienced during manual patient handling (Garg & Owen, 1992; Zhuang et al., 1999). A comparison between ceiling lifts and floor lifts for a set of patient transfer activities found that the ceiling lifts generated lower spinal loads than the tolerance threshold limits for endplate fractures (Marras et al., 2009).

The majority of the focus of existing research with respect to patient handling has been on the actual transfer process. However, the use of mechanical assistive devices requires the preparation of patients for the transfer by placing a sling under them, as they lie supine on a bed. Similarly, the slings have to be removed from under the patients once the transfer task is completed. The sling application and removal is typically performed
using techniques recommended by sling manufacturers (Ergolet America, 2011; Guldmann, 2013). These sling application and removal activities involve considerable manual handling of the patient in terms of rolling, pushing and pulling of the patient on the bed.

There has been limited research on the biomechanical loads experienced during the sling application and removal process. The compression forces on the L5/S1 joint during the task of manually turning a patient in bed were reported to be as high as 3526 N (Gagnon et al., 1987). Zhuang et al. reported L5/S1 compression load ranges of 2094 - 4367 N when rolling a patient towards the nurse and 1804 – 4745 N when rolling a patient away from the nurse (Zhuang et al., 1999). However, another study reported that the median compression and shear loading at the L5/S1 joint for the sling application were 1400 N and 250-300 N, respectively (Santaguida et al., 2005). Knapik and Marras reported the presence of extensive A/P shear loading at the upper lumbar levels of the spine during pushing and pulling tasks (Knapik and Marras, 2009). The recommended techniques for the sling application and removal involve considerable manual pushing and pulling of the patient. Hence, there is a need to study the biomechanical loads experienced during sling application and removal at all the levels of the lumbar spine.

Given that the shear loading on the spine during pushing and pulling tasks was found to increase with increased weight that was being handled (Knapik & Marras, 2009), the biomechanical loading during sling application and removal is expected to be sensitive to patient weight. Other critical facets of the sling application process that can influence its ergonomics are the method used and the height of the bed when the sling
application or removal occurs. Studies have shown improved spine posture and spine
kinematics when the bed height was adjusted to a nurse-preferred height for patient
handling activities (De Looze et al., 1994; Caboor et al., 2000).

The recommended technique for the sling application by a single nurse can essentially be split into five tasks –

a) Rolling the patient away from the nurse by a pushing action
b) Spreading a half of a rolled up sling onto the bed
c) Rolling the patient towards the nurse by a pulling action
d) Spreading the other half of the sling on the bed and
e) Rolling the patient supine back onto the sling.

While all these tasks can be performed from one side of the bed, it is possible that the nurse could walk around the bed to complete the latter three tasks of the process. This converts the sling application process into an activity consisting only of pushing tasks as opposed to the one-sided technique, which has both pushing and pulling tasks. One study demonstrated lesser compressive forces on the L5/S1 joint during the pushing tasks than the pulling tasks that are involved in patient handling (Zhuang et al., 1999).

Further, to simulate the worst case loading scenario nurses can experience while handling patients, this study was designed to assess the spine loading for a one-person sling application activity for a patient who cannot provide any assistance to the nurse during the sling application or removal process.
2.1.2 Aims and Hypotheses:

The purpose of the research is to quantify the biomechanical loads on the spine, when nursing personnel perform the ancillary processes of patient lifting sling application and removal and to determine if this process generates spinal loading that can contribute to the onset of low back pain in nurses. Specifically the aim of the study is to investigate the effects of three factors hypothesized to influence the loading on the spine during these tasks: the sling application and removal method, the bed height, and the weight of the patient. Specifically, this study tested the following hypotheses:

1. Raising the bed height reduces the spine loading during sling application and removal.

2. Having the nurse work on both sides of the bed during the sling application and removal reduces the biomechanical loading of the spine.

3. A heavier passive patient leads to greater biomechanical loads during the sling application and removal that those experienced with a lighter passive patient.
2.2. Methods:

2.2.1 Subjects

Twelve participants were recruited for the study. Three were professional nurses, three were nursing assistants and six were nursing students. The average age, height and weight of the subjects were 26.8 (SD = 4.01), 168.4 cm (SD = 2.91) and 73.33 Kg (SD = 15.83) respectively. Inclusion criteria required participants be between the ages of 18 and 65 years, that they were not pregnant, they had no case of low back pain lasting for more than 24 hours in the previous 12 months, and that they were not experiencing pain from any other injury in the previous year that prevented them from performing any physical activity. All participants signed a consent document approved by the University's Institutional Review Board.

2.2.2 Experimental Design

The experiment consisted of a nurse applying the sling and removing it from underneath two simulated patients of different weights. For each weight condition, the bed height was varied to three different levels. At each level, the sling was applied and removed using two methods. Thus, the independent variables for the experiment were the patient weight, the sling application and removal method, and the height of the bed. The
dependent measures for the study were measured separately for both the sling application and removal activities.

The patient weight levels were fixed at 54 Kgs and 100 Kgs. Both the patient volunteers were instructed and trained not to assist the nurse during the sling application or removal. This was done to simulate a worst-case scenario of sling use by nurses.

Three bed height levels were evaluated. The lowest and highest heights (56 cm and 93 cm from the floor to the top of the mattress) represent the end ranges of adjustment on the bed were used in this study. In addition, each individual subject’s standing knuckle height was chosen as the third height level. Specifically, the knuckle height was defined as the height from the floor to the proximal inter-phalangeal joint of the right hand as the participant stood erect with their arms handing at their sides.

Two methods of sling application and removal were also investigated. The “One-sided” method involved the nurse standing only on one side of the bed while performing the sling application and removal. This technique involved both the activities of pushing the patient away from the nurse and pulling the patient towards the nurse to roll the patient and spread the sling on the bed. The “Two-sided” method involved the nurse walking over to the far side of the bed for the latter half of the sling application and the first half of the sling removal. This technique involved only the task of pushing the patient away from the nurse during rolling of the patient. Both techniques of sling use required the nurses to lift the strapped legs of the patient to put the leg support straps of the sling under them.
2.2.3 **Spine Load Predictions**

The compression, anterior/posterior shear, and lateral shear forces at the superior and inferior endplate levels between T12/L1 to L5/S1 of the lumbar spine were predicted by a subject specific, biologically assisted biomechanical model. This model has been in development at the Biodynamics Laboratory at The Ohio State University over the past several decades. The model is suitable for any activity involving three-dimensional free dynamic lifting, pushing and pulling. The model uses subject specific anthropometry, body kinematics, task performance kinetics, and surface electromyographic (EMG) data.

2.2.4 **Apparatus**

The sling used for the study was a multipurpose sling (OriginalSling, Hill-Rom, Chicago, IL, USA) with full back support and straps for supporting the legs. The sling was used on a bed (Total-Lift Bed, VitalGo Systems Ltd., Fort Lauderdale, FL, USA) on which the patient laid supine. The sling was applied and removed using techniques recommended by manufacturers (Ergolet America, 2011; Guldmann, 2013). To simulate a worst-case scenario where the patient remained completely passive, straps were wrapped around the patient’s arms and legs to prevent individual movement of arms and legs. The straps were made of Velcro material and did not cause any discomfort to the patients. The arms of the patients were crossed across the chest under the strap during the sling application and removal.
EMG data were captured bilaterally using 10 bipolar surface electrodes from the erector spinae, latissimus dorsi, internal oblique, external oblique and rectus abdominus muscles. The location of electrodes has been described earlier. (Mirka & Marras, 1993). The signals from the electrodes were captured using a Model 12 Neuradata Acquisition System (Grass Technologies West Warwick, RI, USA). Task kinetics in the form of ground reaction forces and moments were measured using two force plates (Bertec 4060A, Worthington, OH, USA). Full body kinematics for the subject were estimated using a three dimensional motion capture system (Optitrack Motive, Natural Point Inc., Corvallis, OR, USA). Passive reflective markers, attached to different anatomical positions on the subject’s body, were used during the motion capture process. A 20lb medicine ball was used for calibration exertions required to calibrate the biomechanical model to each specific subject.

Data from the EMG system, kinetic data from force plates and motion capture data from the tracking system are channeled using a PCI - 6031E Data Acquisition System (National Instruments, Austin, TX, USA) by a Customized Laboratory Information Management System developed at the OSU Biodynamics Laboratory.

2.2.5 Procedure

After obtaining informed consent, anthropometric measures were obtained from the subject to prepare for the calibration of the model. Surface EMG electrodes were applied to the subject’s trunk muscles after skin preparation. Impedance was measured across the bipolar electrodes at each trunk muscle site to ensure adequate electrode
sensitivity. Tracking markers were put on the subject at different anatomical locations. The subjects were then asked to perform a series of calibration exertions while standing on the force plates. These data were used to calibrate the open loop biomechanical model. The subjects were given opportunity to practice the sling application and removal using the techniques being investigated. The patient weight conditions and the sling application techniques were counterbalanced between different subjects and the bed height conditions were randomized between sessions.

2.2.6 Data Analysis

The raw EMG data collected during the experiments were pre-amplified, low pass filtered at 1000Hz, high pass filtered at 15 Hz and then passed through a 20ms sliding window filter. The data were further smoothened using a Hanning smoothing filter. The dynamic EMG signal was used by the model to compute dynamic muscle forces. The model produced estimated peak compression and shear forces at the superior and inferior endplate for each disc level between T12/L1 and L5/S1. For each disc level, the superior and inferior endplate forces were compared and whichever was greater was used in the subsequent statistical analyses.

The initial statistical analysis involved use of a multivariate ANOVA (MANOVA) analysis to evaluate the main effects and interactions looking collectively at the data from each disc level. The Wilks-Lambda statistic has been used as a test criterion for identifying significances of main effects and any relevant interactions. Any interactions of significance were further evaluated by univariate analysis of variance
using post-hoc analysis to check for any significant differences between different levels of a variable. A post-hoc REGWQ test was conducted to verify for significant differences between the different pairs of bed height conditions. A significance level of 0.05 was chosen for all the analyses.
2.3. Results:

2.3.1 Model Performance

The biomechanical model’s performance was continuously monitored during data collection using the R squared correlation and the normalized Average Absolute Error mentioned earlier. The average R squared correlation across the different sessions was 0.85 (SD = 0.07) and the AAE averaged across the different sessions was 0.087 (SD = 0.03).

2.3.2 Multivariate Analysis

Table 1 shows the p-values from the Wilks’-Lambda criteria for the MANOVA test evaluating the independent variables and their interactions. Table 2 shows the p-values from the subsequent univariate analyses for the dependent measures that showed significant differences for the factors considered in the multivariate analysis. The compression, A/P shear and lateral shear forces showed significant differences between the two levels of patient weights. All the levels of the lumbar spine considered showed significant differences between the two levels of patient weight, as shown in Table 2. This pattern was found for both the sling application and the sling removal.
Table 1: p-values for the Wilks’ Lambda criterion from multivariate ANOVA for the main effects and subsequent interactions

<table>
<thead>
<tr>
<th>Factor</th>
<th>Activity</th>
<th>Compression</th>
<th>A/P Shear</th>
<th>Lateral Shear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>Apply</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Height</td>
<td>Apply</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Method</td>
<td>Apply</td>
<td>NS</td>
<td>&lt;0.0001</td>
<td>0.0008</td>
</tr>
<tr>
<td>Weight*Height</td>
<td>Apply</td>
<td>NS</td>
<td>0.03</td>
<td>NS</td>
</tr>
<tr>
<td>Height*Method</td>
<td>Apply</td>
<td>NS</td>
<td>0.01</td>
<td>0.008</td>
</tr>
<tr>
<td>Weight*Method</td>
<td>Apply</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Weight<em>Height</em>Method</td>
<td>Apply</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Weight</td>
<td>Remove</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Height</td>
<td>Remove</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>NS</td>
</tr>
<tr>
<td>Method</td>
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<td>&lt;0.0001</td>
<td>NS</td>
</tr>
<tr>
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<td>NS</td>
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</tr>
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</tr>
<tr>
<td>Weight*Method</td>
<td>Remove</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Weight<em>Height</em>Method</td>
<td>Remove</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

2.3.3 Effects of Patient Weight

Figure 2 shows the pattern of loading and differences between the two levels of patient weight variables for the three dependent measures of interest. Compression forces were significantly higher for the sling use for the heavier patient than the lighter patient. This trend was observed at all the lumbar end plate levels with the forces being about 800-1000N higher for the heavier patient. The highest loading was observed at the L3/L4
inferior level and the L4/L5 superior level for both the patient weight conditions. This pattern was observed for both sling application and removal. Relative to the lighter patient, the heavier patient resulted in significantly higher A/P shear forces across all the lumbar endplate levels with the highest differences being approximately 400 N at the L5/S1 level during both sling application and removal. For the rest of the lumbar vertebral levels, the differences were between 150-200 N for the sling application task and between 50-100 N for the sling removal task. The heavier patient weight also generated consistently higher lateral shear loads, with the loading consistently increasing more for the superior disc levels and by as much as 300 N at the T12/L1 level during the sling application.
Table 2: p-values for univariate ANOVA analyses at the different vertebral disc endplate levels

<table>
<thead>
<tr>
<th>Factor</th>
<th>Activity</th>
<th>Compression</th>
<th>A/P Shear</th>
<th>Lateral Shear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
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<td>&lt;0.0001 (all)</td>
<td>&lt;0.0001 (all)</td>
<td>&lt;0.0001 (all)</td>
</tr>
<tr>
<td>Height</td>
<td>Apply</td>
<td>&lt;0.0001 (all)</td>
<td>&lt;0.0001 (all)</td>
<td>0.02 (all except L5/S1)</td>
</tr>
<tr>
<td>Method</td>
<td>Apply</td>
<td>NS</td>
<td>&lt;0.0001 (all except L4/L5, L5/S1)</td>
<td>0.01 (all except L4/L5, L5/S1)</td>
</tr>
<tr>
<td>Weight*Height</td>
<td>Apply</td>
<td>NS</td>
<td>NS</td>
<td>0.02 (L5/S1)</td>
</tr>
<tr>
<td>Weight*Method</td>
<td>Apply</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Height*Method</td>
<td>Apply</td>
<td>NS</td>
<td>0.002 (T12/L1, L1/L2, L2/L3)</td>
<td>NS</td>
</tr>
<tr>
<td>Weight<em>Height</em>Method</td>
<td>Apply</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Weight</td>
<td>Remove</td>
<td>&lt;0.0001 (all)</td>
<td>&lt;0.0001 (all)</td>
<td>&lt;0.0001 (all)</td>
</tr>
<tr>
<td>Height</td>
<td>Remove</td>
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<td>&lt;0.0001 (all)</td>
<td>0.01 (L5/S1)</td>
</tr>
<tr>
<td>Method</td>
<td>Remove</td>
<td>0.002 (all)</td>
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<td>NS</td>
</tr>
<tr>
<td>Weight*Height</td>
<td>Remove</td>
<td>NS</td>
<td>NS</td>
<td>0.02 (L5/S1)</td>
</tr>
<tr>
<td>Weight*Method</td>
<td>Remove</td>
<td>NS</td>
<td>0.009 (L3/L4)</td>
<td>NS</td>
</tr>
<tr>
<td>Height*Method</td>
<td>Remove</td>
<td>0.02 (all)</td>
<td>0.002 (T12/L1, L1/L2, L2/L3)</td>
<td>NS</td>
</tr>
<tr>
<td>Weight<em>Height</em>Method</td>
<td>Remove</td>
<td>NS</td>
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</tr>
</tbody>
</table>
Figure 2: Dependent measures for the ‘Weight’ factor at considered vertebral disc endplate levels for the sling application and removal. Mean peak forces with standard deviations are shown. An “*” next to the bars indicates significant differences
(a) Mean Compression Force - Application (b) Mean A/P Shear Force - Application
(c) Mean Lateral Shear Force - Application (d) Mean Compression Force - Removal
(e) Mean A/P Shear Force – Removal (f) Mean Lateral Shear Force - Removal
Continued
2.3.4 Effects of Bed Height

Significant differences were observed for the compression, A/P shear, and lateral shear forces between the three bed height levels for sling application and for compression and A/P shear forces during the sling removal (Figure 3). For compression and A/P Shear, significant differences across bed height conditions were prevalent for all the lumbar disc levels considered. In the case of lateral shear, the significant differences were present for all disc levels except L5/S1 for sling application and only for L5/S1 for sling.
removal. Post-hoc REGWQ tests were conducted to compare the differences in loading between pairs of the bed height levels. These are shown graphically in Figure 3. For both the application and removal tasks, compression forces were significantly different for all the pairs of bed heights at all the lumbar vertebral levels. The highest compression forces were observed in the lowest bed height level and the magnitude of the force generally proved to be inversely proportional to the height of the bed. With each change in the bed height level, compression forces varied in the order of 300 – 400 N for sling application and 500 – 600 N for sling removal.

During sling application, A/P shear was significantly reduced at the 71 cm bed height as compared with the 56 cm bed height for all disc levels except L2/L3 and further reduced at all disc levels except T12/L1 when the bed height was further increased to 93 cm. During sling removal the A/P shear forces were also generally reduced with higher bed levels.

As for the lateral shear forces, increasing the bed height from 56 to 71 cm increased these shear forces at most disc levels during sling application, but not for sling removal. However, the lateral shear only increased by approximately 100 N as bed height increased from 56 cm to the knuckle height for sling application. The largest differences were approximately 100 N at the more superior disc levels. There were no significant changes between knuckle height and the 93 cm level for sling application. During sling removal, the lateral shear forces were generally low and not significantly affected by the bed height.
Table 3: Lumbar Intervertebral disc endplate levels at which the specified pairwise comparisons of bed heights have significant differences as per post-hoc REGWQ tests

<table>
<thead>
<tr>
<th>Pairwise Comparison</th>
<th>Activity</th>
<th>Compression</th>
<th>A/P Shear</th>
<th>Lateral Shear</th>
</tr>
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<tbody>
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<td>56 cm - 71 cm</td>
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<td>All</td>
<td>All except L2/L3</td>
<td>All except L5/S1</td>
</tr>
<tr>
<td>56 cm - 93 cm</td>
<td>Apply</td>
<td>All</td>
<td>T12/L1, L3/L4, L4/L5, L5/S1</td>
<td>L1/L2, L2/L3, L3/L4, L4/L5</td>
</tr>
<tr>
<td>71 cm – 93 cm</td>
<td>Apply</td>
<td>All</td>
<td>All except T12/L1</td>
<td>NS</td>
</tr>
<tr>
<td>56 cm - 71 cm</td>
<td>Remove</td>
<td>All</td>
<td>All except L4/L5</td>
<td>NS</td>
</tr>
<tr>
<td>56 cm - 93 cm</td>
<td>Remove</td>
<td>All</td>
<td>T12/L1, L3/L4, L4/L5, L5/S1</td>
<td>L5/S1</td>
</tr>
<tr>
<td>71 cm – 93 cm</td>
<td>Remove</td>
<td>All</td>
<td>All except T12/L1, L1/L2, L2/L3</td>
<td>L5/S1</td>
</tr>
</tbody>
</table>
Figure 3: Dependent measures for the “Height” factor at considered vertebral disc endplate levels for the sling application and removal. Mean peak forces with standard deviations are shown. An “*” next to the bars indicates significant differences.
(a) Mean Compression Force - Application (b) Mean A/P Shear Force - Application
(c) Mean Lateral Shear Force - Application (d) Mean Compression Force - Removal
(e) Mean A/P Shear Force – Removal (f) Mean Lateral Shear Force - Removal

Continued
Figure 3: continued
2.3.5 Effects of Sling Application Method

During sling application only the A/P Shear and Lateral shear forces were found to change significantly across the two sling application methods (Figure 4). This significance was prevalent at all the disc levels except L4/L5 and L5/S1. For A/P shear in sling application, the differences between methods were less than 100 N despite statistical significance for T12/L1, L1/L2, L2/L3 and L3/L4. In the case of lateral shear, for the upper four lumbar levels, sling application generated more loading using the one sided method over the two sided method. This difference was of the order of 100 – 150 N.

For sling removal, the differences were significant between methods for compression and A/P Shear at all the lumbar vertebral levels. The differences in compression stem from the two-sided method generating, on average, approximately 300 N more compression force than the one-sided method. The A/P shear observed during sling removal saw statistical significance between the two methods, but the differences were only of the order of 100 N except for L5/S1. The sling removal task did not show any significant differences in lateral shear between the two methods.
Figure 4: Dependent measures for the “Method” factor at considered vertebral disc endplate levels for the sling application and removal; Mean peak forces with standard deviations are shown. An “*” next to the bars indicates significant differences

(a) Mean Compression Force - Application  (b) Mean A/P Shear Force - Application
(c) Mean Lateral Shear Force - Application  (d) Mean Compression Force - Removal
(e) Mean A/P Shear Force – Removal  (f) Mean Lateral Shear Force - Removal

Continued
Figure 4: continued
2.3.6 Interactions between Independent Variables:

Only the Height versus Method interaction showed significance in MANOVA and subsequent ANOVA for A/P shear. This significance was seen for both sling application and removal. For sling removal only, the weight versus height interaction showed significance for lateral shear.

Figures 5 and 6 show the mean A/P shear forces, for the sling application and removal respectively, at all the lumbar vertebral levels for the height versus method interaction. The one-sided method showed an increase in shear loading as bed height increased from knuckle height to 93 cm at the L2/L3 level. The two-sided method showed a consistent decrease in magnitude as bed height increased. This interaction was found significant in the T12/L1, L1/L2 and L2/L3 levels for both sling application and removal. However, the difference in shear loading between the two methods at knuckle height and above remained under 100 N. The difference between the two methods was higher at the 56 cm height level though for some vertebral levels, with the two-sided method generating up to 200 N more shear at this lower bed height.

During sling removal, the lateral shear L5/S1 was higher for the heavier patient at the lowest bed height and was reduced as the bed became higher whereas there was essentially no change in the lateral shear force for the lighter patient at this disc level at the higher bed heights.
Figure 5: Mean A/P Shear forces for the Method versus Height interaction for Sling Application at the considered lumbar vertebral levels. Lines show trends of peak loading with standard errors. An “*” indicates significant differences in ANOVA
(a) T12/L1  (b) L1/L2  (c) L2/L3  (d) L3/L4  (e) L4/L5  (f) L5/S1
Figure 6: Mean A/P Shear forces for the Method versus Height interaction for the Sling Removal at the considered lumbar vertebral levels. Lines show trends of peak loading with standard errors. An “*” indicates significant differences in ANOVA.

(a) T12/L1  (b) L1/L2  (c) L2/L3  (d) L3/L4  (e) L4/L5  (f) L5/S1
Figure 7: Mean Lateral Shear forces for the Weight versus Height interaction for the Sling Removal at the considered lumbar vertebral levels. Lines show trends of peak loading with standard errors. An “*” indicates significant differences in ANOVA.

(a) T12L1  (b) L1/L2  (c) L2/L3  (d) L3/L4  (e) L4/L5  (f) L5/S1
2.3.7 Magnitude of Loading:

For sling application, with the 100 Kgs patient, mean peak compression forces at several lumbar vertebral levels approached 3400 N, which is the stipulated tolerance threshold. A similar scenario was seen with A/P shear at L4/L5 and below and for lateral shear at L2/L3 and above. Hence, concern of spinal injury risk exists during sling application with heavier patients. The A/P Shear at L5/S1 also exceeded the threshold limits for the heavier patient during sling removal.

During sling application at the bed height level of 56 cm, the mean peak compression forces at several vertebral levels exceeded the 3400 N. The L5/S1 level generated A/P shear loading that crossed threshold limits for shear loading at all the bed height levels. This pattern was observed for both sling application and removal. For lateral shear loading, the mean peak forces crossed tolerance thresholds at L1/L2 and above for sling application irrespective of bed height.

For both the sling application methods, A/P Shear loading at L5/S1 crossed the threshold limits for both the application and removal tasks. For sling application alone, the lateral shear loading at L1/L2 and above exceeded the tolerance thresholds.

Figures 8 and 9 show the percentages representing the samples of subjects from among the entire research participants that had experienced loading which exceeded the tolerance limits. These figures further the understanding of the prevalence of spinal injury risk in the sling application and removal tasks. The compression at L4/L5, A/P shear at L5/S1 and lateral shear at T12/L1 were the chosen parameters for these figures as they represented the points most likely to experience excessive loading. For the heavier
patient, about 80 percent of the subjects experienced loading that exceeded the threshold values for L4/L5 Compression and T12/L1 lateral shear for the sling application process. All the subjects experienced L5/S1 shear exceeding the threshold values for both sling application and removal.

When the bed height was 56 cm, about 70 percent of the subjects experienced compression exceeding the threshold limits. The percentage of subjects experiencing elevated T12/L1 lateral shear at this height was observed to be above 80. Again, L5/S1 A/P Shear was found to be above the threshold limits for all the subjects recruited for the study, across all the bed height conditions. With decreasing height, there was a reduction in the extent of subjects experiencing elevated compression but lateral shear did not show any such trends. Thus, these figures show that there is a significant risk of spine injury through L5/S1 A/P shear, irrespective of experimental conditions, for the sling application and removal tasks.
Figure 8: Percentages of subjects experiencing loading greater than the tolerance threshold limits for both the patient weight conditions.

(a) L4/L5 Compression – Sling Application  (b) L4/L5 Compression - Sling Removal
(c) L5/S1 A/P Shear – Sling Application  (d) L5/S1 A/P Shear – Sling Removal
(e) T12/L1 Lateral Shear – Sling Application  (f) T12/L1 Lateral Shear – Sling Removal
Figure 9: Percentages of subjects experiencing loading greater than the tolerance threshold limits for all the bed height conditions.

(a) L4/L5 Compression – Sling Application  
(b) L4/L5 Compression - Sling Removal  
(c) L5/S1 A/P Shear – Sling Application  
(d) L5/S1 A/P Shear – Sling Removal  
(e) T12/L1 Lateral Shear – Sling Application  
(f) T12/L1 Lateral Shear – Sling Removal
2.4. Discussion:

2.4.1 Loading Scenario:

One of the primary objectives of this study was to quantify the biomechanical loads on the spine in all three directions of loading and compare these measures against the tolerance threshold limits for vertebral endplate damage initiation. Overall, the mean compression at all the lumbar vertebral levels for the sling removal remained under the recommended threshold value of 3400 N. However, with the sling application task, the mean compression value across subjects, with the heavier patient, exceeded the 3400 N threshold level at several vertebral endplate levels. A similar trend was seen at the L1/L2 level and the T12/L1 level for the lateral shear loading, in the case of sling application. A/P Shear loading at the L5/S1 level consistently exceeded the upper threshold limit of 1000 N for shear loading. It should also be noted that there was considerable variability across this sample of female participants in their estimated spinal loads. The standard deviations shown in the figures show that there were many conditions where the disc tolerance thresholds for compression and shear were exceeded by at least part of the sample. Other observations show that 60 – 80 percent of the sample was subjected to compression and lateral shear loading that was greater than the tolerance threshold limits. In the case of A/P Shear, this number was a 100 percent. In sum, these data signify the
risk of initiation of low back pain through endplate damage that is prevalent with the sling application and removal process.

The higher patient weight significantly increased compression, A/P shear and lateral shear loading. This might be related to the increased demand on the nurse in terms of weight that was to be pushed or pulled while rolling the patient. Further, with the heavier patient there was an increase in the weight that was to be lifted while placing the leg supports of the sling under the patient’s legs. Marras et al. (2009) found increased shear loading with increase in patient weight when lift systems with loaded slings were pushed. The heavier weight for the patient employed in the study was slightly higher than the average U.S. male weight for an adult, 20 years or older, as stipulated by the Centers for Disease Control and Prevention (U.S. Department of Health and Human Services, 2012). Hence, it can be suggested that this biomechanical loading scenario is fairly plausible in a healthcare setting. Worse conditions may be reasonably expected in healthcare settings with patients who are closer to the top 10th percentile male persons in terms of weight.

The activity of sling application had significantly higher compression, A/P shear and lateral shear loading than the activity of sling removal. This can be attributed to the greater accuracy and thoroughness that the sling application task demands. The nurses had to roll the patients and hold them steadily on their sides with one hand as they spread the sling on the bed with the other hand. The back of the sling needed to be properly spread under the patient while ensuring that the center of the sling back aligns with the spine of the patients. The tasks demands were also high when the nurse puts the leg
supports of the sling under the legs of the patient. In contrast, the sling removal required the rolling of the patient only enough to allow the sling to be grabbed and pulled out swiftly, reducing the need for a more sustained exertion of push or pull forces by the nurse. Also with the sling removal, the nurses did not need to lift the legs of the patient to remove the leg supports, which also further reduced exertion demands for the sling removal activity. Thus it may be advised that the nurses exercise extra awareness during the sling application than the removal with regards to body postures and ergonomics.

Compression, A/P shear and lateral shear forces significantly varied with the different bed heights for sling application. For sling removal, only compression and A/P shear varied significantly with changes in height. Varying the bed height varied the postural demands on the nurses and modified the ergonomics in terms of reach distance, hand-force application height and the forward external moment on the spine. The largest compression and A/P shear loading, which was observed at the lowest bed height, could be attributed to increased spine flexion during the sling application and removal tasks. Santaguida et al. (2005) reported that in the sling application activity, spine loading for the nurses happened ‘in a manner similar to 45 degree leaning’. There was generally a linear reduction of spine loading magnitude with the stepwise increase in bed height. Lateral shear loading did not show any significant differences, in a biomechanical context, across height levels for the sling removal. This suggests that during the primary force applications the loading was generally symmetric across the coronal plane, and this symmetric response was unaltered across different bed height levels.
The two-sided and one-sided sling application and removal methods chiefly differed in two ways. First, the two-sided method replaced the pulling exertion in the one-sided method with an additional pushing task. Second, with the two-sided method the nurses needed to pull the railings up on the first side of the bed and put them down on the second side of the bed before rolling the patient from the other side. This was imperative as it prevented the patients from falling off of the bed during the rolling activity.

Observation of the temporal characteristics of loading in this method showed that there were peaks in compression, A/P shear and lateral shear loading as the nurses operated the railings with flexed and laterally bent spine postures. However, this is a specific characteristic of the operation of the bed used in the study, as the handles for the operation of railings were set very low. Further observation of temporal characteristics of the loading in both the sling application methods showed equivalent spine compression and shear forces for both the pushing and pulling tasks involved in rolling the patients. Thus, loading in either method seemed to occur as a systemic effect of the different tasks involved in the methods. Loading estimation for individual tasks within each method was not done in this study. But, this allowed for a realistic replication of the sling application process in the laboratory.

The interaction between the methods and bed heights showed that at the highest bed height (93 cm), the A/P Shear was higher with the one sided method than with the two-sided method. The opposite trend was observed at both the knuckle height level and the lowest height level of the bed at 56 cm. The awkward postures induced by the activity of using the railings were more pronounced with the lowest and knuckle height levels of
the bed, prompting higher loading for the two-sided method. This was especially applicable to A/P Shear loading, which is highly sensitive to pronounced flexion, owing to a straighter lumbar spine and the gravitational force vector. Thus a recommendation may not be made in favor of the two sided method over the one sided method.

2.4.2 Biomechanical effects:

The pushing and pulling efforts in the sling application and removal tasks requires the trunk muscles to exert both agonistic and antagonistic forces to retain trunk composure and meet application of force. This results in an elevated exertion of the trunk muscles with more anterior/posterior orientations, namely the internal and external oblique muscles, thus leading to increased anterior-posterior shear forces. A majority of the pushing and pulling efforts made in the study were observed at increased spine flexion. This posture, combined with the torso musculature generating push or pull forces resulted in higher A/P shear loading at the lower lumbar levels as reported earlier. In addition, the increased thoroughness of the sling application process also entails considerable lateral bending and twisting of the spine. This increases exertion of trunk muscles that are aligned laterally, the obliques again, thus leading to generation of lateral shear loading on the spine. Similarly, Marras et al. (2009) showed increased shear loading when pushing and pulling floor and ceiling patient lifts.

Earlier studies that investigated loading on the spine during patient rolling activities as part of the patient preparation phase published loading measures related to the L5/S1 joint. The compression forces at the L5/S1 joint for patient rolling ‘towards’
the nurse and ‘away’ from the nurse were estimated in the ranges of 2094-4367N and 1804-4745N respectively (Zhuang et al., 1999). However, this study utilized a static biomechanical model to arrive at the loading measures. In the present study, the compression forces ranged from 1340 – 4535 N. This range of forces is similar, therein suggesting that there were limited dynamic influences in this task. Another study estimated the loading at the L5/S1 joint during the sling application activity to be a compression of only 1400 N (Santaguida et al., 2005). The same authors reported shear loads of only 250-300 N (Santaguida et al., 2005). In contrast, the shear loads reported in the present study ranged from 200 – 2130 N. This difference in shear loading could be captured in this study as the model used for the study captured coactivity of muscles. Coactivity of trunk muscles can greatly enhance loading on the spine, which is often not captured by models that do not include muscle coactivity assessment.

2.4.3 Study Recommendations:

This study evaluated bed heights of 56 cm, knuckle height (mean = 71 cm) and 93 cm. With the exception of the A/P shear loading on the L5/S1 level and the lateral shear loading on the T12/L1 level, the maintenance of bed height at the knuckle level or higher was shown to lower spine loads below the tolerance thresholds. Caboor et al. (2000) noted that when nurses were given an opportunity to adjust bed height, a standard deviation of only 0.064 m was observed over a pre-set height of 0.515 m. Further, another study reported a standard recommended height level of 0.715 m from the floor to the top of the mattress (de Looze et al., 1998). Thus, an objective workplace
recommendation can be made for patient beds to be adjusted in height, at least to knuckle height, based on the observations of this study. There is a possibility of greater loading in the shoulders and arms when a bed height of 93 cm is used. However, this was not assessed in this study.

Recommendations may be made in terms of patient sling redesign so that the number of times the sling application and removal needs to be done can be reduced. Pre-study work observations suggested that nurses typically encounter 8 – 10 sling application and removal trials per shift. Providing one sling per patient may also be an option but there could be possible stigma related to hygiene in a typical healthcare setting.

The loading scenario that was seen in this study may be altered when two nursing personnel use a sling to move a patient. It was not possible to design this study so that the sling application can be compared between a one-nurse method and a method involving two nurses. However, it can be expected that inclusion of a second nurse in the process could potentially reduce the applied forces, depending upon how the team coordinates their activities during this task. Marras et al. (1999) showed that, with a two person manual transfer, the compression and lateral shear forces were consistently reduced as compared to a one-person transfer process. From an administrative perspective, the allocation of a second nursing personnel for the sling application process may be recommended.
2.4.4 Study Limitations:

One of the limitations of this study was that all the subjects recruited were female. As such, there was no opportunity to understand the loading scenario for a male spine for the activities being studied. However, since census statistics suggest that only nine percent of the total nursing personnel are men, the results of this study are reasonably sufficient to represent the general nursing population (U.S. Census Bureau, 2013). Another limitation for this study was the utilization of only one nurse for the sling application in each session and the lack of an opportunity to study a two-nurse sling application process. It could be the scope of future research to verify the recommendations and concerns highlighted in this study in a comparison between one nurse and two nurse sling application processes. Another limitation of this study was that the sample size was not sufficient enough to thoroughly validate the absence of significance in some of the interactions.

Finally, the findings of this study are generalizable to the nursing population within the confines of the conditions employed in this study. The measures obtained may vary depending on the type of sling, bed or other equipment used. However, efforts have been made to design the study to be consistent with pre-study work observations so that the study was representative of the sling application and removal tasks that nurses can expect to encounter.
CHAPTER 3: CONCLUSION

This study aimed to evaluate the process of patient lifting sling application and removal that is essential for the use of mechanical lifting aids used for transferring patients. These lifting aids have proven to be effective interventions in the control of spine loading in nurses during patient transfer. The overall loading indicated that A/P Shear at the L5/S1 level and Lateral shear at the L1/L2 level and above in the lumbar spine were greater than the spine tolerance threshold limits of 750 N suggested in the literature (McGill, 1997). Compression forces exceeded the tolerance threshold of 3400 N for the heavier patient condition and the lowest bed height condition (NIOSH, 1981). The loading along the three dimensions consistently increased with patient weight for both the sling application and removal. Compression and A/P Shear showed significant decrease in magnitude as bed height increased, therein suggesting that nurses should be trained to raise the bed to at least knuckle height prior to working with the sling. Lateral shear was significantly different across heights only for the top four lumbar levels. Thus, the hypothesis that raising the bed height reduces spine loading during sling application and removal was satisfied by this study. The hypothesis that a heavier passive patient leads to greater biomechanical loads than a lighter passive patient during sling application and removal was satisfied. The hypothesis that having the nurse work on two sides of the bed reduces the biomechanical loading was not satisfied. Changing the method of sling
application and removal from a one-sided method to a two-sided method has shown only a slight increase in the Compression and A/P Shear and a slight decrease in the Lateral shear. Thus, this alternative technique cannot be recommended. Finally, given that the loads were generally higher during the sling application, as opposed to its removal, it would be more important for nurses to seek assistance during the application task, particularly with heavy patients.
BIBLIOGRAPHY


Guldmann. (2013). *Custom Sit On High - Sling On/Off in bed*. Retrieved from https://www.youtube.com/watch?v=pHNrxfoXbOs&index=1&list=PLbAilBrSQQFHZeCfY5lp5gwGzk5VQ4


Table 4: Mean values (Standard Errors in parenthesis) of three-dimensional forces at all the vertebral disc endplate levels across all conditions for sling application

<table>
<thead>
<tr>
<th>Endplate Level</th>
<th>Compression (N)</th>
<th>A/P Shear (N)</th>
<th>Lateral Shear (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T12L1 Superior</td>
<td>2837.88 (65.44)</td>
<td>616.69 (16.36)</td>
<td>880.79 (25.64)</td>
</tr>
<tr>
<td>T12L1 Inferior</td>
<td>2855.30 (65.55)</td>
<td>590.36 (15.85)</td>
<td>764.87 (22.42)</td>
</tr>
<tr>
<td>L1L2 Superior</td>
<td>2864.48 (65.91)</td>
<td>611.00 (16.04)</td>
<td>769.52 (22.57)</td>
</tr>
<tr>
<td>L1L2 Inferior</td>
<td>2888.50 (65.93)</td>
<td>537.81 (14.01)</td>
<td>652.98 (19.38)</td>
</tr>
<tr>
<td>L2L3 Superior</td>
<td>2897.86 (66.11)</td>
<td>561.91 (14.82)</td>
<td>656.75 (19.55)</td>
</tr>
<tr>
<td>L2L3 Inferior</td>
<td>2928.54 (66.07)</td>
<td>392.38 (10.25)</td>
<td>546.42 (16.63)</td>
</tr>
<tr>
<td>L3L4 Superior</td>
<td>2945.61 (66.08)</td>
<td>388.46 (9.54)</td>
<td>549.59 (16.79)</td>
</tr>
<tr>
<td>L3L4 Inferior</td>
<td>2961.95 (66.11)</td>
<td>312.99 (7.02)</td>
<td>430.64 (13.93)</td>
</tr>
<tr>
<td>L4L5 Superior</td>
<td>2955.27 (65.72)</td>
<td>480.72 (8.97)</td>
<td>432.94 (14.11)</td>
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<td>L4L5 Inferior</td>
<td>2917.03 (65.55)</td>
<td>664.38 (11.42)</td>
<td>398.32 (13.00)</td>
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<tr>
<td>L5S1 Superior</td>
<td>2768.37 (62.76)</td>
<td>1170.99 (22.09)</td>
<td>400.12 (13.13)</td>
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<tr>
<td>L5S1 Inferior</td>
<td>2620.72 (60.84)</td>
<td>1468.73 (28.05)</td>
<td>415.95 (13.14)</td>
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</tbody>
</table>
APPENDIX B: MEAN FORCE VALUES – SLING REMOVAL

Table 5: Mean values (Standard Errors in parenthesis) of three-dimensional forces at all the vertebral disc endplate levels across all conditions for sling removal

<table>
<thead>
<tr>
<th>Endplate Level</th>
<th>Compression (N)</th>
<th>A/P Shear (N)</th>
<th>Lateral Shear (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T12L1 Superior</td>
<td>2485.85 (65.37)</td>
<td>516.69 (13.84)</td>
<td>593.83 (18.36)</td>
</tr>
<tr>
<td>T12L1 Inferior</td>
<td>2506.02 (65.44)</td>
<td>498.67 (13.54)</td>
<td>516.17 (15.87)</td>
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<tr>
<td>L1L2 Superior</td>
<td>2519.69 (65.76)</td>
<td>505.54 (12.35)</td>
<td>519.82 (15.92)</td>
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<td>L1L2 Inferior</td>
<td>2533.74 (65.80)</td>
<td>448.26 (10.88)</td>
<td>443.40 (13.42)</td>
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<td>L2L3 Superior</td>
<td>2546.55 (65.95)</td>
<td>461.30 (10.81)</td>
<td>446.66 (13.45)</td>
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<td>L2L3 Inferior</td>
<td>2565.93 (66.08)</td>
<td>325.58 (7.44)</td>
<td>377.51 (11.08)</td>
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<tr>
<td>L3L4 Superior</td>
<td>2581.13 (66.06)</td>
<td>333.05 (7.88)</td>
<td>378.97 (11.11)</td>
</tr>
<tr>
<td>L3L4 Inferior</td>
<td>2587.20 (66.15)</td>
<td>294.12 (6.51)</td>
<td>311.07 (8.58)</td>
</tr>
<tr>
<td>L4L5 Superior</td>
<td>2577.44 (66.72)</td>
<td>451.93 (8.48)</td>
<td>312.91 (8.57)</td>
</tr>
<tr>
<td>L4L5 Inferior</td>
<td>2540.71 (65.58)</td>
<td>608.94 (10.87)</td>
<td>293.87 (7.49)</td>
</tr>
<tr>
<td>L5S1 Superior</td>
<td>2404.09 (62.79)</td>
<td>1056.80 (21.74)</td>
<td>295.69 (7.48)</td>
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<tr>
<td>L5S1 Inferior</td>
<td>2274.09 (60.96)</td>
<td>1308.68 (27.52)</td>
<td>305.56 (7.56)</td>
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</table>