

The Roles of Lumbar load thresholds in lifetime cumulative lifting exposure to predict disk protrusion in Asian

Isabella Yu-Ju Hung

Chung Hwa University of Medical Technology <https://orcid.org/0000-0003-4568-9983>

Tiffany Ting-Fang Shih

Department of Medical Imaging and Radiology, National Taiwan University Hospital

Bang-Bin Chen

Department of Medical Imaging and Radiology, National Taiwan University Hospital

Ing-Kang Ho

Center of Drug Abuse and Addition, China Medical University Hospital

Saou-Hsing Liou

Division of Environmental Health and Occupational Medicine, National Health Research Institutes

Yue Leon Guo (✉ leonguo@ntu.edu.tw)

<https://orcid.org/0000-0002-8530-4809>

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Abstract

Background: The purpose of this study was to determine whether if a specific threshold value exists in each lifting load, the accumulation above which best predicts lumbar disk protrusion, or on the other hand, all lifting load should be accumulated. **Methods:** This was a retrospective study. Subjects with various lifetime lifting exposures were recruited. Disk protrusion was determined by magnetic resonance imaging. Lifetime cumulative lifting load was the sum of time-weighted lumbar load for each job using a biomechanical software system. For accumulation above different thresholds, predictive capabilities for disk protrusion were compared using four statistical methods. **Results:** A total of 252 men and 301 women were included in the final analysis. For men, 3000 Newton for each lifting task was the optimal threshold value for predicting L4-S1 disk protrusion, whereas for women, 2800 Newton was optimal. Our findings suggested that when considering lifetime exposure, including all lifting loads without defining a minimal exposure limit might not be the optimal method for predicting disk protrusion. **Conclusions:** The NIOSH 3400 Newton recommended limits do not appear to be optimal threshold for preventing disk protrusion. Different lifting thresholds might be applied to men and women in the workplace for safety.

Background

Numerous studies have found relationship between occupation workload and disk protrusion [1-8], which may lead to sciatica, low back pain (LBP), and even long-term disability. Disk protrusion has been listed as an occupational disease and compensated in many countries, such as Denmark, France, Germany, United States, and Taiwan[7]. Recent decades, researchers have reported that lifetime cumulative lifting load has been related to disk protrusion in a dose-dependent manner [5-8]. However, lifting objects with various weights is inevitable in everyday work and life. A crucial question is whether a specific threshold value exists in each lifting load, the accumulation above which best predicts lumbar disk protrusion, or on the other hand, all lifting load should be accumulated.

A review of the literature revealed several recommended lifting thresholds, although most of them were used in the prevention of low back injury [9-16]. For example, the National Institute for Occupational Safety and Health (NIOSH) of the United States suggested that if spinal compression exceeds approximately 3400 N (Newton), workers would be at an increased risk of low back injury [17]. Nevertheless, those recommended lifting limits might not be practicable for calculating the cumulative effects for several reasons. First, they were examined for a single spontaneous lifting and the career-long effects of repeated lifting were not considered. Second, most of them were proposed for preventing LBP, not for to disk protrusion. Third, the safe manual lifting threshold value of 3400N recommended by NIOSH doesn't appear to be optimal as currently, more than 50% of work-related low back injuries are attributed to manual lifting tasks [18]. Fourth, uniform lifting limits are not generalizable across ethnicity and sex. Accordingly, this study was conducted to determine the optimal lifting threshold per lift for calculating the lifetime cumulative load in order to prevent disk protrusion in Asian, and to determine whether the threshold value differs between men and women.

Methods

Study Population

This was a retrospective study. The protocol and consent forms of the study were reviewed and approved by the National Taiwan University Hospital Research *Ethics Committee* (NTUH-REC No.:200805047R). Recruitment of the participants, measurements of the work exposure, and imaging studies of the lumbar spines were detailed elsewhere [8]. To obtain a broad spectrum of lifting exposures, the participants were recruited from 2 populations: (1) 263 walk-in clinic patients and (2) 452 workers who carry heavy loads. Patients visited the Internal Medicine Clinic of National Taiwan University Hospital and diagnosed with upper respiratory infections (URI), mostly the common cold, were recruited as the background population. The group that carried heavy loads were workers from one fruit and vegetable wholesale market. Lifting is a daily routine task for these workers. During recruitment, the market workers and the walk-in patients were not informed of the hypothesis of the study. They were invited to participate in an investigation regarding spine and bone disorders. The inclusion criteria were between 20 and 65 years old and at least 6 months of working experience. Participants diagnosed with several health conditions described previously were excluded [8]. We combined these 2 populations to examine the effects of lifting on disk protrusion. Before participating in the study, all workers and patients received written and oral information regarding the study procedures and potential adverse effects, and signed informed and published consent forms. Of these eligible 715 subjects, 162 were excluded from this study for the following reasons: 84 people experienced cancer, 27 people had major back trauma, 18 people had compression fractures, 16 people had psychiatric conditions, 13 people had spinal tumors, and 4 people had inflammatory spondylopathy.

Data Collection

Each participant was asked to complete a questionnaire and to obtain magnetic resonance imaging (MRI) of the lumbar spine. A detailed structured interview was implemented to the participants for assessing the relevant work tasks in each job held since they entered the workforce. The occupational history included job titles, tenures, body weights at each job, descriptions of tasks, carry load, lifting frequency and duration, working hours per day and working days per week. The participants were encouraged to recall their body weights during the period of each job. When the job period was longer than 5 years, the average body weight during this job period was used.

Estimation of Lumbar Disk Compression Load

The method of lumbar disk compression load estimation has been published previously [8]. Regarding the estimation of lifetime exposure, the participants recalled all of the jobs held after completing schooling, and the weight, frequency, and duration of each task. The participants performed a typical

material handling task to simulate the positions and weights encountered at each job. Lifting activity was divided into a sequence of static postures, including the initial lift-up, transferring, and unloading postures, and each posture was analyzed. The initial position of the weight lifting task was defined as the lift-up posture, the final position was defined as the unloading posture, and the action of transferring material while walking was defined as the transferring posture. Although the initial and final positions of lifting may have varied during a typical day of materials handling on the job, the selected typical tasks, including the simulated positions and weights, were used to calculate the compression load to represent the job. The compression load on the disk during lifting was estimated using the 3D Static Strength Prediction Program (3DSSPP, University of Michigan, Michigan) software system [19,20]. Anthropometric data such as sex, height, body weight, carried weight, and working posture photograph of each participant were input into the system to predict lumbar load. To evaluate the intrarater and interrater reliability of lumbar load estimation by 3DSSPP, photographs of the simulated work conditions of the 60 study participants were repeatedly evaluated in 2 rounds, with the second round of evaluation was conducted 4 weeks after the first round.

Definition of Threshold in This Study

The threshold value in this study was defined as lumbar load per lift and above this proposed value was considered as contributed to disk protrusion over an entire career life, and was included in the lifetime cumulative calculation. In other words, the calculation neglected all exposures with a lumbar load below the threshold. The proposed threshold values were set at zero Newton (N), and at 100N increments from 2000 to 4000N.

Calculation of Lifetime Cumulative Lifting Exposures on the Lumbar Disk

The calculation method of lifetime cumulative lifting exposures on the lumbar disk was modified from the Mainz-Dortmund dose model (MDD), which is based on overproportional weighting of the lumbar disc compression force relative to the corresponding duration of lifting, and was applied by several studies [5,6,7,8].

To investigate the actual cumulative lifting exposure, the participants recalled details regarding lift-up time ($t_{\text{lift-up}}$), transporting time ($t_{\text{transporting}}$), and unloading time (t_{unload}) of each lifting task at their jobs. Hence, in this study, the lifting exposure of each task was defined as the sum of the products of the lift-up lumbar load ($F_{\text{lift-up}}$) and the corresponding lift-up time, the products of the transporting lumbar load ($F_{\text{transporting}}$) and the corresponding transporting time, and the products of the unloading lumbar load (F_{unload}) and the corresponding unloading time. Only those lumbar loads greater than proposed threshold value were eligible into the lifetime cumulative exposure calculation. For example, if the threshold value

is set at 0 N, every lifting load generated from each activity will be included in the calculation. And, when the threshold value is set as 3400 N, only exposures with a lumbar load per lift above

3400 N will be eligible in the calculation. For each job described, the lifting exposure was calculated as the sum of product of the lifting load and the corresponding duration of lifting in hours (Newton × hour, Nh). The lifetime cumulative lifting exposures for each participant was then calculated by summing the lifting exposure on the lumbar disk from all jobs.

The calculation method was expressed as the following equation:

Cumulative lifting exposures_(Newton × hour) =

$$\sum [(F_{\text{lift-up}}(\text{Newton}) \times t_{\text{lift-up}}(\text{second}) + F_{\text{transporting}}(\text{Newton}) \times t_{\text{transporting}}(\text{second}) + F_{\text{unload}}(\text{Newton}) \times t_{\text{unload}}(\text{second})) \times 1_{(\text{minute})}/60_{(\text{second})} \times 1_{(\text{hour})}/60_{(\text{second})} \times \text{frequency of lifting/day} \times \text{working days/year} \times \text{working year}]$$

where F represents the lifting load (Newton) on the lumbar disk and t represents time (seconds).

An example of the calculation of the sum of lifting exposures is given as below:

One male worker with 170 cm body height and 75 kg body weight reported that he had carried object 1 (weighting 10kg, lift up for 1 second, walking for 30 seconds, and unload for 1 seconds), 100 times a day; and object 2 (weighting 20kg, lift up for 1.5 second, walking for 10 seconds, and unload for 1.5 seconds), 50 times a day, working 220 days a year. The total work tenure had been 20 years.

Estimation of lumbar force by 3D SSPP

		Estimated lumbar force (Newton)			Duration for one task (second)		
		lift-up	walking	unload	lift-up	walking	unload
	weight						
Object 1	10 Kg	3713	1667	3713	1	30	1
Object 2	20 Kg	4858	2343	4858	1.5	10	1.5

Calculation of cumulative lifting exposure:

1. When the threshold is set at 0 N, the cumulative exposure is as following:

$$\{[(3713 \times 1) + (1667 \times 30) + (3713 \times 1)] \times 100 +$$

$$[(4858 \times 1.5) + (2343 \times 10) + (4858 \times 1.5)] \times 50 \} \times 220 \times 20 / 3600 =$$

9.3×10^6 (Newton-hours)

The calculation result indicated that this person is categorized into the intermediate lifting group ($1.8 \times 10^6 \sim 1.6 \times 10^7$ Newton-hours).

2. When the threshold is set at 3000 N, the cumulative exposure is as following:

$$\{[(3713 \times 1) + (3713 \times 1)] \times 100 +$$

$$[(4858 \times 1.5) + (4858 \times 1.5)] \times 50\} \times 220 \times 20 / 3600 =$$

1.79×10^6 (Newton-hours)

The calculation result indicated that this person is categorized into the intermediate lifting group ($2.5 \times 10^5 \sim 5.6 \times 10^6$ Newton-hours).

3. When the threshold is set at 3400 N, the cumulative exposure is as following:

$$\{[(3713 \times 1) + (3713 \times 1)] \times 100 +$$

$$[(4858 \times 1.5) + (4858 \times 1.5)] \times 50\} \times 220 \times 20 / 3600 =$$

1.79×10^6 (Newton-hours)

The calculation result indicated that this person is categorized into the intermediate lifting group ($0 \sim 4 \times 10^6$ Newton-hours).

4. When the threshold is set at 4000 N, the cumulative exposure is as following:

$$[(4858 \times 1.5) + (4858 \times 1.5)] \times 50\} \times 220 \times 20 / 3600 =$$

8.9×10^5 (Newton-hours)

The calculation result indicated that this person is categorized into the intermediate lifting group ($0 \sim 4 \times 10^6$ Newton-hours).

Regarding to the categorizing of the lifetime cumulative exposure, we try to divide the participants into low, intermediate and high cumulative lifting load group by tertile in male/female populations. However, only lift-up forces greater than proposed threshold value were included into lifetime calculation. Thus, higher the threshold developed, more participants were categorized in the low lifting group. Therefore, in male population, the cumulative exposure with 3000 N and 0 N thresholds above were categorized into low, intermediate, and high tertiles. For the cumulative exposure with 3400 N and 4000 N thresholds above, the low group was those with 0 Nh, and intermediate and high group were dichotomized among those with cumulative loads above 0 Nh. On the other hand, In female population, the cumulative exposure with 0 N threshold above was categorized into low, intermediate, and high tertiles. For the

cumulative exposure with 2800 N, 3400 N, and 4000 N thresholds above, the low group was those with 0 Nh, and intermediate and high group were dichotomized among those with cumulative loads above 0 Nh.

The reproducibility of the lifting measurements was tested 6 months after the initial interview with the help of 25 participants. Their current jobs were used for reliability testing. These measurements included the working tenure, lifting weights, frequency of lifting per day, and lift-up time of the job. After observing and recording the fruit workers' practices, we found that most of the participants' lift-up time was almost equal to their unloading time and that the transporting time was zero. Therefore, the reliability of the transporting time and unloading time was not examined. In addition, we determined that pushing or pulling is not a common task for the majority of fruit market workers because they typically drive an electric pedicab to transfer fruit boxes. Therefore, the lumbar load of pushing and pulling was not assessed.

Each intervertebral disk at L4–L5 to L5–S1 was evaluated for disk bulging, protrusion, extrusion, and sequestration using MRI. All MRI examinations were conducted at the National Taiwan University Hospital. MRI equipment and protocol, definition of disk condition, the evaluation of intrarater reliability regarding the presence or absence of protrusion were described previously [8]. Two radiologist were responsible for the image interpretation and were blinded for the lifting exposure status of the participants.

Data Analysis

The reproducibility of the calculation of the lifting load and lifting measurements was analyzed using SPSS version 16.0 for Windows (SPSS Inc, Chicago, Illinois) to compute intraclass correlation coefficients (ICCs). Kappa was used to assess the intrarater reliability of disk protrusion on MRI. Logistic regression analysis using JMP 5.0 (SAS Institute Inc, Cary, North Carolina) was applied to identify the association between lifetime cumulative lifting load and disk protrusion at either of the lower disk levels, namely, L4-L5 and L5-S1 disk. Each variable was examined to determine the influence on the disk protrusion and was considered to be a potential confounder as having a statistically significant association ($p < 0.05$). Thus, the logistic regression was adjusted for age, BMI, and history of smoking. Odds ratio (OR) and 95 % confidence intervals were calculated by logistic regression analysis. To determine the best threshold of lifting load, four statistical values were used to compare outcome (L4-S1 disk protrusion) to lifetime cumulative load while different threshold values was applied, namely, (1) Area under the curve (AUC) of a receiver operating characteristic (ROC) curve, (2) Coefficient of determination (R^2), (3) Akaike information criterion (AIC), and (4) Bayesian information criterion (BIC). We compared the AUC in various models that were plotted using MedCalc for Windows Version 9.2.1.0 (MedCalc Software, Mariakerke, Belgium). Models with higher AUC statistics were considered as the optimal model. The amount of cumulative lifting load explained by various threshold values in the model was evaluated based on the R^2 statistic. AIC and BIC were obtained using SAS Version 9.1 (SAS Institute Inc.) AIC is closely related to BIC. Given a

set of candidate models for the data, the preferred model is the one with the minimal AIC value, and the same applies to BIC.

Results

A total of 553 volunteers were included in the final analysis; 252 participants were men (mean age 49.8 years, standard deviation (SD): 11.7) and 301 were women (mean age 51.3 years, SD: 9.4). The demographic characteristics of the participants are shown in Table 1. The men exhibited higher BMI values (25.6 ± 3.1 kg/ m²) than women did (24.1 ± 3.8 kg/ m²), and most participants had more than 15 years of work experience (75.6%). LBP during the past 6 months was reported by approximately 83.6% of the participants. The reproducibilities of lifting measurements were high for working tenure (ICC = 0.943), lifting weights (ICC = 0.945), and frequency of lifting per day (ICC = 0.914), and moderate for lift-up time (ICC = 0.743). The intrarater and interrater reliabilities of lifting load calculation were 0.998 and 0.992 (ICC), respectively. The Kappa value of intrarater reliabilities for L4-S1 disk protrusion was good with 0.850.

Figure 1 and Figure 2 showed the predictive abilities of lifetime liftload with different threshold to L4-S1 disk protrusion in male and female participants, respectively.

The detail information were shown in Supplemental Table 1 and Supplemental Table 2. With any of the threshold values, the lifetime cumulative lifting load was significantly associated with L4-S1 disk protrusion. Among the male participants, the maximal AUC (0.686) was found while lifting load of 3000N was used as threshold (Figure 1(a) and Supplemental Table 1). The R^2 statistic (0.0797), AIC (-390.3), and BIC (-387.8) were also optimal when 3000N (Figure 1(b), (c), (d) and Supplemental Table 1). The ROC curves of 3400N, 3000N, and 0N models in male were showed in Figure 3. Among the female participants, the maximal AUC (0.615) was found while lifting load of both 2800N and 3000N were used as threshold (Figure 2(a) and Supplemental Table 2). The R^2 statistic (0.0321), AIC (-501.1), and BIC (-498.6) were also optimal when 2800N (Figure 2(b), (c), (d) and Supplemental Table 2). The ROC curves of 3400N, 2800N, and 0N models in female were showed in Figure 4.

Table 2 and 3 showed adjusted odds ratios (aORs) for disk protrusion when lifetime cumulative load was calculated by various thresholds as predictors. In male, the cumulative load with 3000 N and 0 N thresholds were categorized into low, intermediate, and high tertiles. For the 4000 N and 3400 N thresholds, the grouping were low (0 Nh), and dichotomies (intermediate and high) among those with cumulative loads above 0 Nh. The cumulative load of above 3000 N provided most significant association with L4-S1 disk protrusion (aOR = 3.1, 95% Confidence Interval (CI) 1.5–6.7; aOR = 2.9, 95% CI 1.4– 6.2) as compared to those using 0 N, 3400 N, and 4000 N (Table 2). In female, the cumulative load with 0 N threshold was categorized into low, intermediate, and high tertiles. For the 4000 N, 3400 N and 2800 N thresholds, the grouping were low (0 Nh), and dichotomies (intermediate and high) among those with cumulative load above 0 Nh. The cumulative load of above 2800 N provided most significant

association with L4-S1 disk protrusion (aOR = 2.6, 95% CI 1.0-6.2; aOR = 2.7, 95% CI 1.4-5.4; aOR = 2.3, 95% CI 1.1-4.8) as compared to those using 0 N, 3400 N, and 4000 N (Table 3).

Discussion

This study found optimal threshold values of load per lift which allow for best prediction of disk protrusion by cumulating exposures. Cumulative lifting load provided best prediction for L4-S1 disk protrusion when the threshold value was set at 3000N for male, and 2800N for female participants. Furthermore, the study was conducted among Asian population and the results might be more applicable in Asia because uniform lifting limits might not be generalizable across ethnicity and sex.

One of the recommended lifting limits, the NIOSH 3400N, is widely used by ergonomists as well as health and safety practitioners [12,21]. It is based on the studies by Evans and Lisner [22], and Sonoda [23]. These studies show that microfractures of the vertebral cartilage endplates started to happen among cadavers of subjects 60 or more years old, when applying average axial loads of 3400 N. The major limitations of NIOSH 3400 N are that the results are based on cadaver studies and immediate effects on the vertebral cartilage end plate, but not for cumulative effects. Our study is important complement to the NIOSH 3400 N criteria and provides recommendations to long-term lifting limits.

To our best knowledge, only few studies examined dose-effect relationship between lifetime cumulative lifting load and disk protrusion. Seilder [5] conducted a thorough investigation of all past lifting load for the participants. They showed that male workers who had been exposed to $5 - 21.5 \times 10^6$ Nh lifetime lifting load exhibited a 1.7-fold risk of disk protrusion comparing to those exposed to $0 - <5 \times 10^6$ Nh, suggesting cumulative effects of all lifting loads, without threshold, on disk protrusion [5-7]. In a later study [8], participants who had been exposed to high lifting load ($\geq 8.9 \times 10^6$ Nh) exhibited an OR of 2.2 for disk protrusion, as compared to those exposed to a low lifting load ($<4.9 \times 10^5$ Nh). This latter study also assumed no per lift threshold for cumulated load. In this current study, a concept of threshold per lift load was tested, and the result showed that applying certain thresholds provided better prediction in calculating lifetime cumulative load than not. Our findings suggested that when calculating lifetime exposure, including all lifting loads without defining a minimal exposure limit might not be the optimal method for predicting disk protrusion. Besides, the investigation was carried out among Asian population, therefore, the findings of this study might be limited the generalizability to other population.

Considering disk protrusion as the health outcome, male participants seemed to tolerate higher lumbar load than females in a per lift load basis. It is possible that men generally had larger cross-sectional areas in lower lumbar disks than women [24]. The larger areas allowed men to endure higher compression load. Thus, the results of this investigation suggest that different lifting thresholds should be applied to men and women in the workplace for safety.

The strengths of our study were the detail investigation of the lifetime lifting exposure, outcome assessment by using MRI, and applying the concept of threshold per lift to lifetime cumulative lifting load

calculation. However, there were several limitations in this study. First, the AUC, R^2 , AIC, and BIC statistics are the summary scores of prediction using each threshold value. They did not allow for statistical comparisons among the proposed threshold values. Second, we relied on the participants' memories regarding their occupational history and relevant work tasks from several decades ago. Although the repeatability of current job tasks was examined and found to be satisfactory, the reliability of the information pertaining to previous jobs was difficult to determine. In order to enhance reliability, a structured interview was executed to provide the participants with adequate time for recalling the work details of their previous jobs. The trained interviewers used life milestones to help the participants recollect the necessary details, and captured the working simulation photos by following a standard procedure. Studies have indicated that self-reported data did not provide satisfactory validity [25]. However, Pope showed the accuracy of self-reported manual material handling activities and presented satisfactorily accurate results regarding frequency, duration, and amplitude [26]. Direct measurements obtained using work or laboratory simulations yield the most accurate information; however, it is impractical by using such methods in retrospective studies involving relatively large sample sizes.

There is another limitation that we did not consider the lifting load in leisure and home activities. In Kelsey's study [27], it found that there was no association between acute herniation and participating in baseball, softball, jogging, golf, bowling, tennis, swimming or bicycling. Although the other study [28] showed that leisure activities involved gardening, snow clearing, or building of a summer cottage were associated with greater disc degeneration in the upper lumbar levels, in Taiwan snowing and building a summer cottage are rarely happened. Therefore, the risk factor of leisure and home activities were not thoroughly inquired in our study. This might have potentially caused misclassification and error in the cumulative lifting load estimates. The R^2 values in male were ranged from 0.0546 to 0.0797, in female were ranged from 0.0143 to 0.0321, those were very low in the study. The result was consistent with Battie's finding [28]. In the L4-5 and L5S1 region of this study, physical loading only explained 2 % of the variance in disc degeneration. With the addition of age to the model increased the explained variability in disc from 2 % to 9 %, and to 43% with the addition of familial aggregation. Thus, the genetic factors had great amount influence in disc degeneration. It might be the reasons that explanatory power of lifting loading on disc protrusion was small.

Disk protrusion has been reported to be associated with manual handling activity [1-8], which may lead to low back pain. There are also many other potential risk factors may cause disk herniation. However, in Jensen's study [29], they found that 64% of asymptomatic individuals had lumbar disk abnormalities (disk bulge, protrusion, or extrusion). Meanwhile, the cause of low back pain is also multifactorial such as disk degeneration, disk herniation, ligament/tendon damage, muscle strains, manual handling activities, vibration, smoking, and psychological factors. Above these reasons, this is a limitation that we used lifting load as the only measurement to determine the development of disk protrusion even we had adjusted other potential risk factors including age, BMI, smoking status. Although disk herniation is often seen in asymptomatic population, setting a lifting threshold in workplace is important to prevent worker

from low back pain. It could be a useful tool for risk assessment and for prevention purpose to reduce the injuries and medical cost.

In the previous study [8], Hung had examined the associations between lifetime cumulative loads and lumbar disk degeneration and found a dose-response relationship. A further question was raised that each lifting load was attributed to the outcome and should be accumulated. For example, a male worker with 170 cm body height and 75 Kg body weight carried a 2 Kg weight object 5 times a day for 10 years. The compression force to the lumbar disk from this 2 Kg weight object might not contribute to the development of disk protrusion even the workers carried it 5 times every day for 10 years. The cumulative calculation approach by sum up all liftloads could lead to overestimation result. Therefore, we assumed that each disk condition might have the corresponding threshold. The study hypothesis is that there is a specific threshold value exists in each lifting load to developing the disk protrusion. Based on the hypothesis, the study had the attempt to investigate various liftload values to determine the optimal threshold to the disk protrusion. Therefore, liftloads below the threshold were neglected in the cumulative calculation and lead to an zero N-hr as the lifetime cumulative exposure. Thus, those participants were finally enrolled into the low lifting exposure group with zero N-hr. Even they were not really experienced zero N-hr at work. In the establishment of the thresholds, this approach has to eliminate some extent amount of cumulative loading, and it may cause underestimation when interpreting the results.

The intervertebral disk degeneration has a complex multifactorial etiology, and also results in a multitude of disk conditions such as disk herniation. Various risk factors have been reported to be associated with disk protrusion, including ageing, physical loading, vibration, genetic factor and even the interaction of factors above [30]. Kumar [31] reported cumulative load or lifetime exposure to biomechanical loads as an important risk factor for low back pain. In order to determine the lifetime cumulative exposure, we investigated the lumbar compression force the workers exposed to (force), time of exposure (duration), and the repetitive task exposure (frequency). The lifetime cumulative exposure calculation method utilized in this study by multiplying Newtons by time has been used previously by other studies [5-8]. One question was raised that the injury accrued by short duration with high loading might be equivalent to longer duration with low loading by using multiplying Newton by time approach. However, it appears to be the truth that exposure to high magnitude loads causes greater damage to tissues than low magnitude loads. That is one reason we utilized threshold into the multiplying Newton by time approach to confront the long duration with low magnitude loads cases. It is the limitation that this approach may not be the most optimal method of assessing the effects of cumulative loading for musculoskeletal tissues. When exposed to repetitive stresses, musculoskeletal tissues were experienced fatigue failure process of cumulative damage development. The theory of fatigue failure in musculoskeletal tissues may be an important etiological mechanism in the development of disk degeneration and should be considered. In Gallagher's study [32], the authors suggested that there are several established techniques of assessing the effects of cumulative loading using fatigue failure theory. By using these techniques, a dose-response relationship between estimated cumulative damage and musculoskeletal disorders is observed. Such relationships have been demonstrated for the low back, shoulder, and upper extremity. Further research

incorporated with the principles of fatigue failure analysis in cumulative exposure assessments to disk degeneration were needed to be conducted.

Conclusions

In this study, we applied the concept of threshold value per lift into lifetime cumulative lifting load calculation. Our findings suggested that considering all lifting loads into lifetime exposure calculation without defining a minimal exposure limit might not be practical approach for predicting disk protrusion. In addition, the NIOSH 3400N may not be optimal threshold for preventing disk protrusion. Different lifting thresholds might be applied to men and women in the workplace to prevent injury.

Abbreviations

NIOSH: National Institute for Occupational Safety and Health

N: Newton **URI:** upper respiratory infections **MRI:** magnetic resonance imaging

NTUH-REC: National Taiwan University Hospital Research *Ethics Committee*

3DSSPP: 3D Static Strength Prediction Program

Nh: Newton × hour, **L4:** the **fourth lumbar spine vertebra**

L5: the **fifth lumbar spine vertebra** **S1:** the first sacrum spine vertebra

ICCs: intraclass correlation coefficients **BMI:** body mass index

AUC: Area under the curve **ROC:** receiver operating characteristic

AIC: Akaike information criterion **BIC:** Bayesian information criterion

MedCalc: MedCalc Software, Mariakerke, Belgium

JMP: statistic software, SAS Institute Inc, Cary, North Carolina

SPSS : statistic software, SPSS Inc, Chicago, Illinois

R²: Coefficient of determination **SD:** standard deviation

kg/ m²: kilogram per square meter **P:** *p value*

aORs: adjusted odds ratios **CI:** confidence interval

Declarations

Ethics approval and consent to participate

The protocol and consent forms of the study were reviewed and approved by the National Taiwan University Hospital Research *Ethics Committee* (NTUH-REC No.:200805047R). Before participating in the study, all workers and patients received written and oral information regarding the study procedures and potential adverse effects, and signed informed and published consent forms.

Consent for Publication

All subjects signed consent forms for publication before participating in the study.

Availability of data and material

The dataset used for analysis during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

YLG, SHL, TTFS, and IYJH provided concept/idea/research design. YLG and IYJH provided drafting or critically revising the article. YLG, BBC and IYJH provided data collection and analysis. YLG, TTFS and IYJH provided project management. YLG provided fund procurement. TTFS and YLG provided facilities/equipment and consultation. IKH provided institutional liaisons. All authors read and approved the final manuscript and revisions.

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Tables

Table 1. Demographic characteristics of the study participants

Variables	Male, N= 252	Female, N= 301	All, N= 553
	N (%)	N (%)	N (%)
Age, mean \pm SD (years)	49.8 \pm 11.7	51.3 \pm 9.4	50.6 \pm 10.5
< 40	55 (21.8)	37 (12.3)	92 (16.6)
40~<50	51 (20.2)	71 (23.6)	122 (22.1)
50~<60	95 (37.7)	142 (47.2)	237 (42.9)
\geq 60	51 (20.2)	51 (16.9)	102 (18.4)
BMI, mean \pm SD (kg/m ²)	25.6 \pm 3.1	24.1 \pm 3.8	24.8 \pm 3.5
< 24	73 (29.0)	151 (50.2)	224 (40.5)
24~<27	103 (40.8)	93 (30.9)	196 (35.4)
\geq 27	76 (30.2)	57 (18.9)	133 (24.1)
Lifetime work tenure (years)			
< 15	59 (23.4)	76 (25.2)	135 (24.4)
15~<30	82 (32.5)	127 (42.2)	209 (37.8)
\geq 30	111 (44.0)	97 (32.3)	208 (37.7)
missing	0 (0.0)	1(0.3)	1(0.1)
Low back pain (within 6 months)	211 (84.1)	246 (83.1)	457 (83.6)
Cigarette smoking (pack-years)			
0	138 (54.7)	288 (95.7)	426 (77.0)
1~<20	43 (17.1)	13 (4.3)	56 (10.1)
\geq 20	70 (27.9)	0 (0.1)	70 (12.7)
missing	1(0.3)	0 (0.0)	1 (0.2)
Exercise* (Yes)	171 (67.9)	185 (62.5)	356 (65.0)

BMI, body mass index; SD, standard deviation

*Yes means ever having regular exercise for 30 minutes or longer each session, at least one session per week, minimum duration of 3 months, from age of 12 years to the present time.

Table 2. The association between L4-S1 disk protrusion and lifetime cumulative lifting load in male participants

Lifetime cumulative lifting load (Newton-hr)		n	Disk protrusion	
			at lower disk level (L4-S1)	
			AOR	
Only lift load above 4000 N was included	Low	0	137	1
	Intermediate	$0 \sim < 4.0 \times 10^6$	58	1.6 (0.8-3.1)
	High	$\geq 4 \times 10^6$	57	1.9 (1.0-3.8)
Only lift load above 3400 N was included	Low	0	96	1
	Intermediate	$0 \sim < 4.0 \times 10^6$	73	1.6 (0.8-3.3)
	High	$\geq 4 \times 10^6$	83	2.0* (1.0-3.9)
Only lift load above 3000 N was included	Low	$< 2.5 \times 10^5$	84	1
	Intermediate	$2.5 \times 10^5 \sim < 5.6 \times 10^6$	83	2.9*** (1.4-6.2)
	High	$\geq 5.6 \times 10^6$	85	3.1** (1.5-6.7)
lift load above 0 N was included	Low	$< 1.8 \times 10^6$	83	1
	Intermediate	$1.8 \times 10^6 \sim < 1.6 \times 10^7$	84	2.3* (1.2-4.9)
	High	$\geq 1.6 \times 10^7$	85	2.0 (1.0-4.2)
Adjusted for age, BMI, smoking				
Statistically significant: *, $P < .05$; **, $P < .01$; ***, $P < .001$.				

Table 3. The association between L4-S1 disk protrusion and lifetime cumulative lifting load in female participants

Lifetime cumulative lifting load (Newton-hr)		n	Disk protrusion	
			at lower disk level (L45-S1)	
			AOR	
Only lift load above 4000 N was included	Low	0	254	1
	Intermediate	$0 \sim < 2.0 \times 10^6$	24	0.7 (0.2-1.9)
	High	$\geq 2.0 \times 10^6$	23	2.6* (1.0-6.2)
Only lift load above 3400 N was included	Low	0	206	1
	Intermediate	$0 \sim < 2.5 \times 10^6$	47	1.6 (0.7-3.4)
	High	$\geq 2.5 \times 10^6$	48	1.9 (0.9-3.9)
Only lift load above 2800 N was included	Low	0	142	1
	Intermediate	$0 \sim < 1.8 \times 10^6$	79	1.9 (0.9-3.7)
	High	$\geq 1.8 \times 10^6$	80	2.7** (1.4-5.4)
lift load above 0 N was included	Low	$< 1.26 \times 10^5$	99	1
	Intermediate	$1.26 \times 10^5 \sim < 5.6 \times 10^6$	101	2.0 (1.0-4.1)
	High	$\geq 5.6 \times 10^6$	101	2.3* (1.1-4.8)
Adjusted for age, BMI, smoking				
Statistically significant: *, $P < .05$; **, $P < .01$; ***, $P < .001$.				

Figures

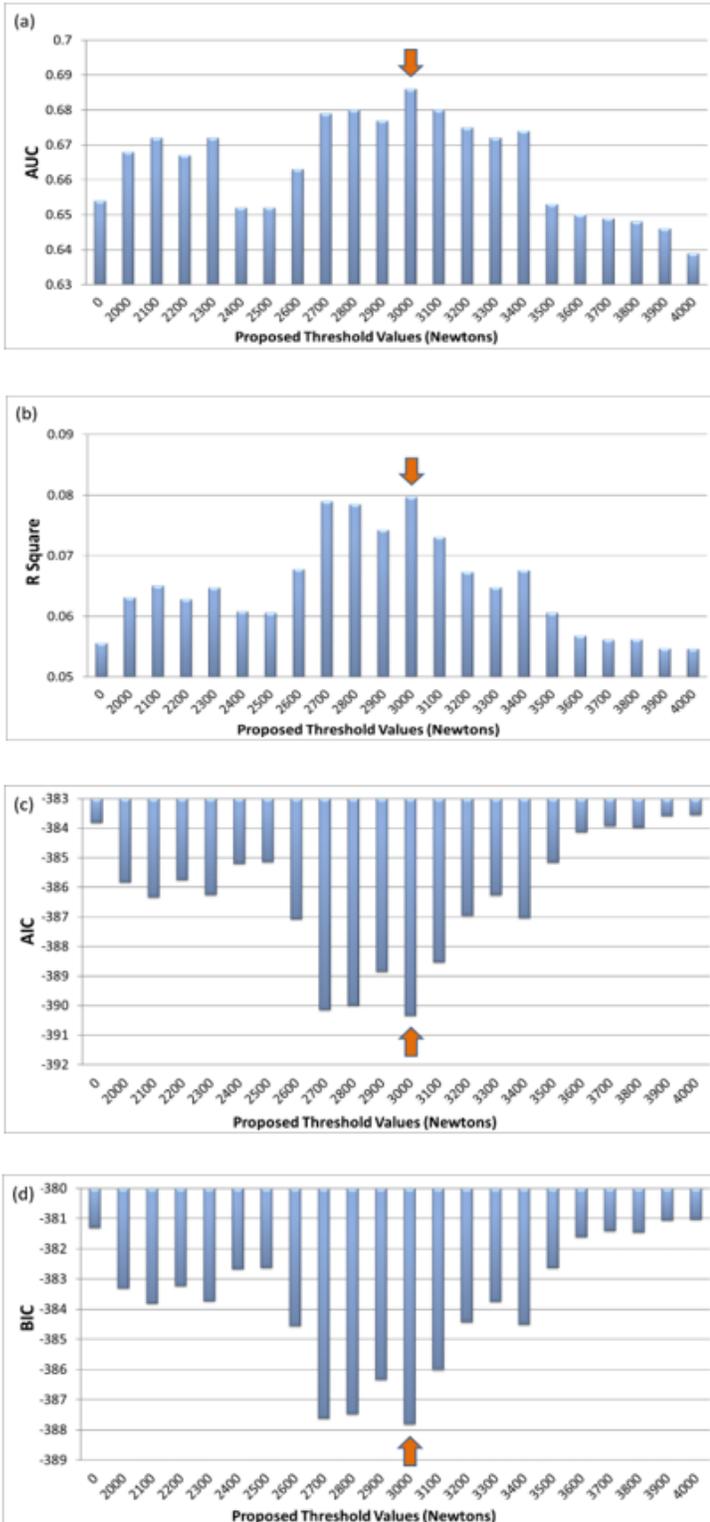


Figure 1

(a). The AUC statistic distribution of L4-S1 disc protrusion with proposed threshold values in male participants (b). The R Square values of L4-S1 disc protrusion with proposed threshold values in male participants (c). The AIC values of L4-S1 disc protrusion with proposed threshold values in male participants (d). The BIC values of L4-S1 disc protrusion with proposed threshold values in male participants

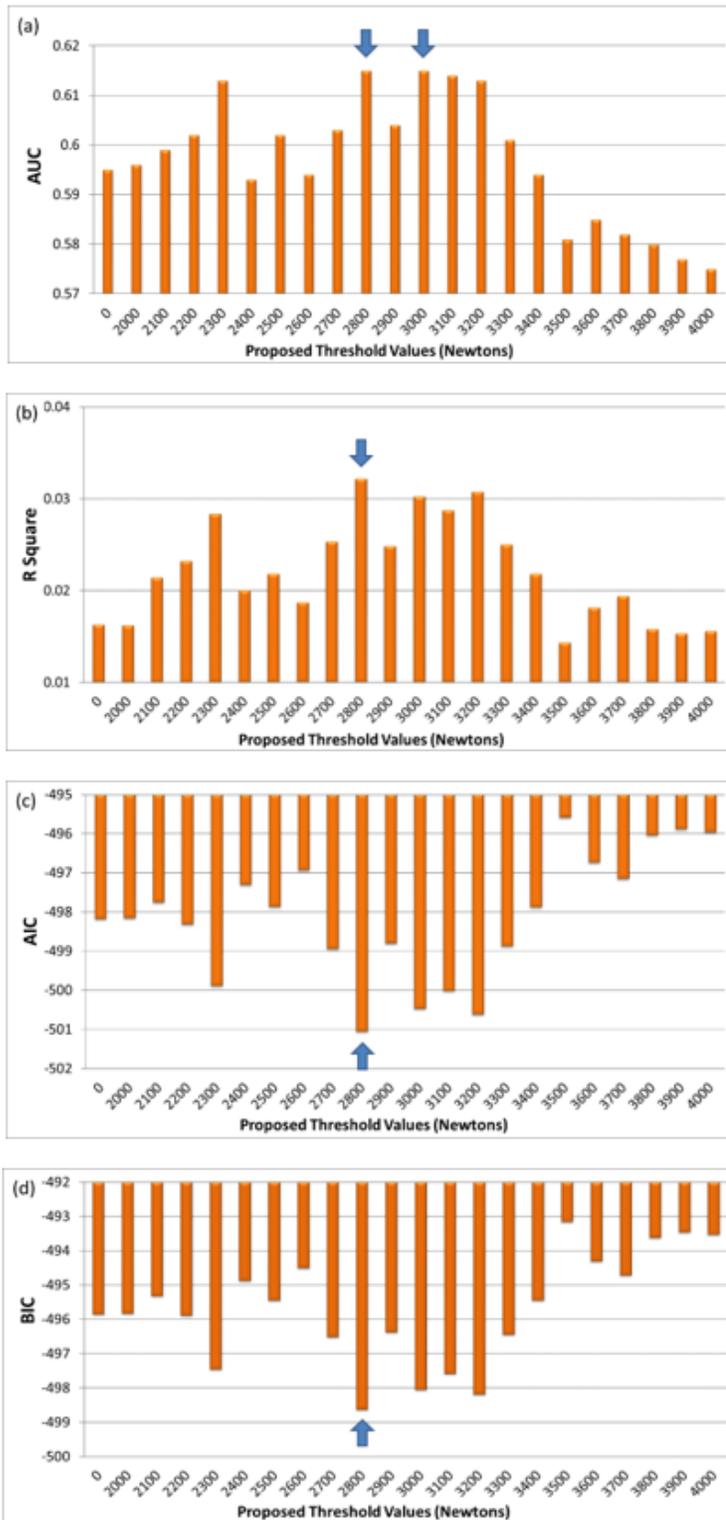


Figure 2

(a). The AUC statistic distrubution of L4-S1 disc protrusion with proposed threshold values in female participants (b). The R Square values of L4-S1 disc protrusion with proposed threshold values in female participants (c). The AIC values of L4-S1 disc protrusion with proposed threshold values in female participants (d). The BIC values of L4-S1 disc protrusion with proposed threshold values in female participants

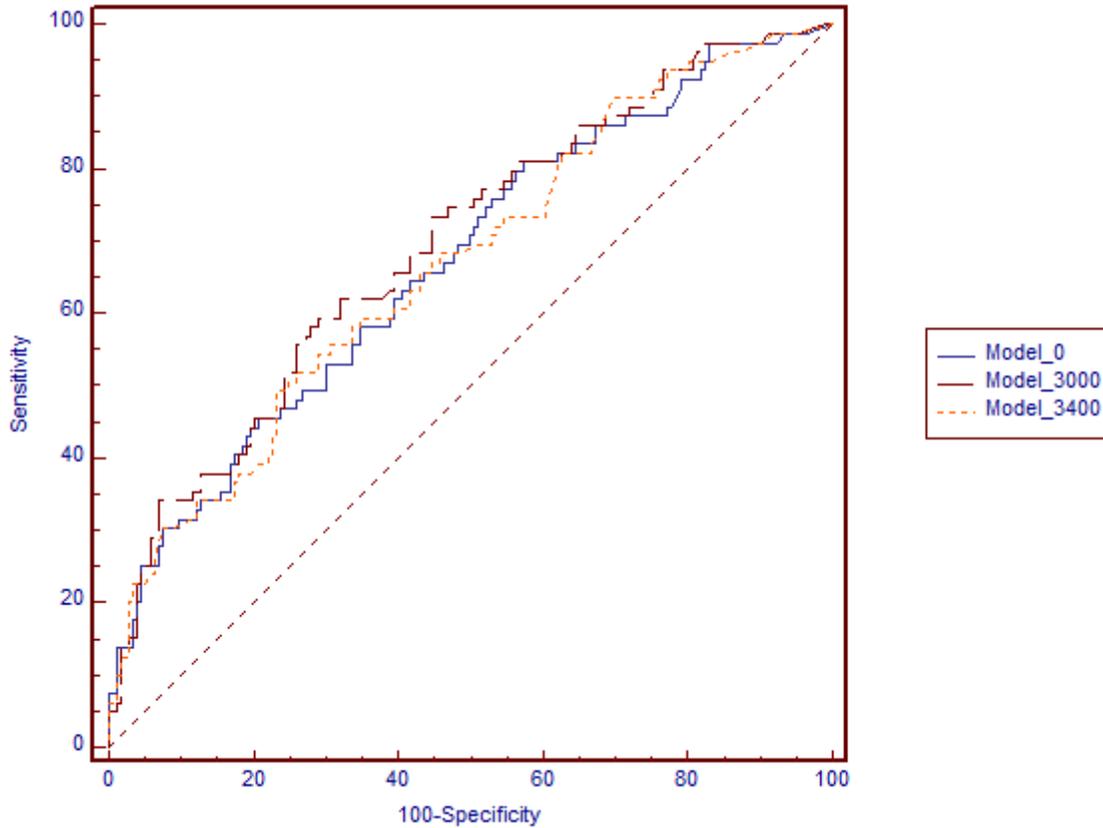


Figure 3

Receiver-operating characteristic curves for the prediction of L4-S1 disc protrusion in male participants by models of different threshold of lifting load. Model 0: AUC (95% CI) = 0.65 (0.61 - 0.71). P = 0.0001 Model 3000: AUC (95% CI) = 0.69 (0.63 - 0.74). P = 0.0001 Model 3400: AUC (95% CI) = 0.67 (0.61 - 0.73). P = 0.0001

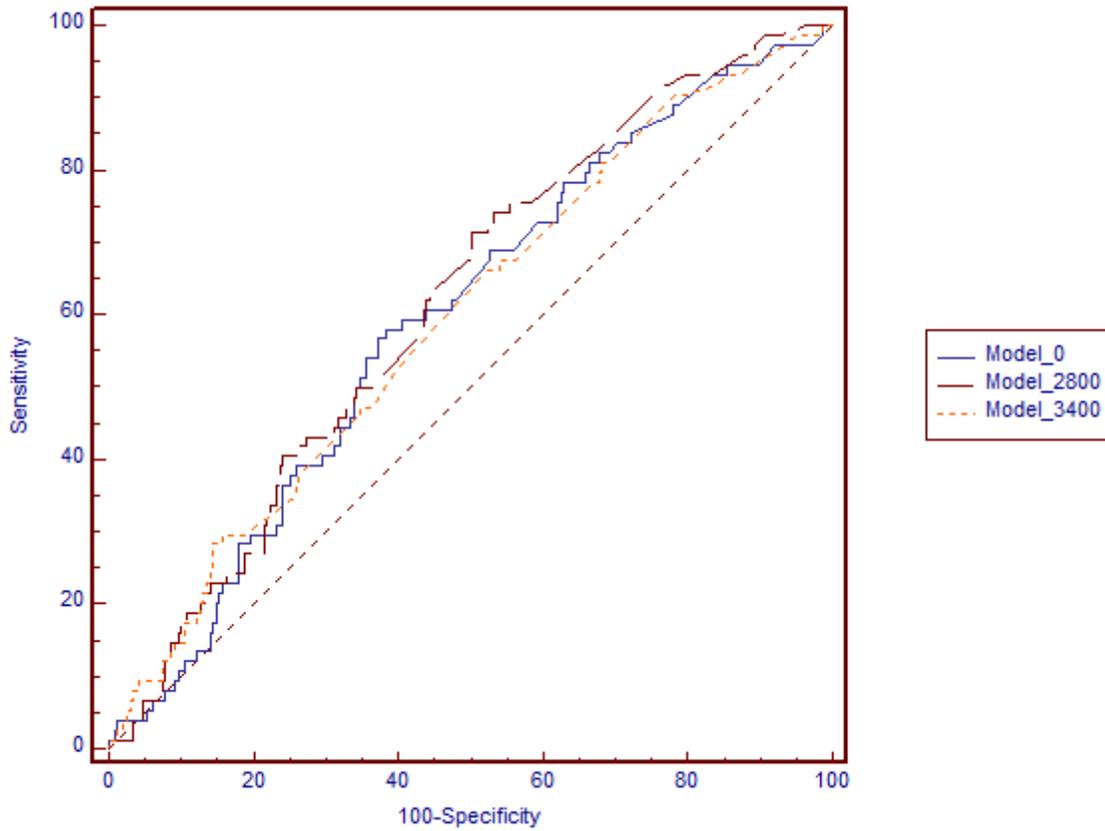


Figure 4

Receiver-operating characteristic curves for the prediction of L4-S1 disc protrusion in female participants by models of different threshold of lifting load. Model 0: AUC (95% CI) = 0.60 (0.54 - 0.65). P = 0.0154
 Model 2800: AUC (95% CI) = 0.62 (0.56 - 0.67). P = 0.0031 Model 3400: AUC (95% CI) = 0.59 (0.54 - 0.65). P = 0.0159