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腰椎椎間盤退化性疾病與終生累積負重之相關性研究

Relationship between Lumbar Disc Degeneration Diseases and Life Time Cumulative Lifting Load

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本論文係洪瑜嬬君（F95841025）在國立臺灣大學職業醫學與工業衛生研究所完成之博士學位論文，於民國 104 年 01 月 08 日承下列考試委員審查通過及口試及格，特此證明

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摘要

前言：

腰椎椎間盤退化性疾病是導致下背疼痛的重要原因之一，在台灣與歐美各國的職業補償統計顯示其高盛行率與發生率所導致的相關失能，造成了醫療與產業成本提高，對於國家的經濟發展是一項沉重的負擔。過去的研究結果顯示職業性負重是椎間盤退化的重要危險因子之一，然而，因為其影響因子之多重性，職業暴露劑量之定量仍有其困難，與椎間盤退化之劑量反應關係尚無定論。因此本研究針對特定高危險性暴露的工作族群，進行詳細的終生累積負重調查，嘗試定量究竟多少終生暴露劑量的搬運重量會造成傷害;且更進一步的調查是否過去所有的負重皆對於傷害的發生有影響？抑或單次負重中存在有著閾值, 超過此值後的累積負重才具危害效應？男女性的閾值是否不同？除了負重之外，椎間盤的形態學(高度與寬度)與椎間盤突出是否具有相關性?若有，是否可以藉由量測椎間盤的高度與寬度來預測椎間盤突出？本研究期望能以此結果應用於職場上作為制定保護勞工健康的累積負重參考基準和預防疾病的發生。

方法：

本研究設計為橫斷性研究，個案來源為 20-65 歲之間的果菜市場搬運工作人員，作為高危險性暴露的工作族群，以及以國立台灣大學附設醫院內科的門診感冒病患，作為一般工作族群。每位受試者均接受一份問卷調查、腰椎

磁共振攝影(MRI)與工作姿勢的模擬取相。為了獲得個案的終身累積負重暴露，研究人員詳細詢問個案過去工作中的搬運重量與時間，現場取相個案所示範的搬運動作，並應用腰椎受力評估軟體(3D SSPP)預測每一個搬運姿勢下的腰椎受力，最終相加所有的腰椎受力與執行搬運的時間乘積，此總和值即為個案的終身累積負重暴露，單位為牛頓×小時(Newton×hour (Nh))。腰椎核磁共振攝影的檢查項目包括五節腰椎之椎間盤缺水(Dehydration)、纖維盤破裂(Annulus tear)、椎間盤變薄(Disc height narrowing)、突出(Bulging or protruding)與脊椎滑脫症(Degenerative spondylolithesis、Spondylolytic spondylolithesis)、椎間孔狹窄(Foramina narrowing)、神經根壓迫(Nerve root compression)，和椎間盤的高度與寬度。統計分析方法以邏輯斯迴歸模式檢視終生累積負重暴露與每一節腰椎之椎間盤退化疾病的相關性。以四種檢驗最適配方程式的統計法來比較各項負重閾值計算下的終生累積負重對椎間盤突出的發生有最佳的預測力。以 ROC 曲線下的面積大小比較二種預測椎間盤突出的預測力: Model 1 以年齡、性別、身高、體重作為危險因子，Model 2 以椎間盤的高度、寬度、年齡、性別、身高、體重作為危險因子。

結果：

共有 715 位自願者參與本研究，最後進行資料分析者為 553 位。研究結果顯示，終身累積負重與腰椎椎間盤退化疾病之間具有顯著相關，同時並呈現有暴露劑量-效應模式。其中，高負重暴露者(≥ 8.9×10^{6}Nh)相較於低負重者(< 4×10^{5}Nh)其第五節腰椎發生椎間盤缺水的危險性是 2.5 倍(AOR=2.5,

CI=1.5,4.1)，椎間盤變薄的危險性是 4.1 倍(AOR=4.1,95% CI=1.9,10.1)；中度負重暴露者(4×10^5-8.9×10^6Nh)相較於低負重者發生椎間盤突出(Bulging)的危險性是 2.1 倍(AOR=2.1,95% CI=1.3,3.3)。超過閾值以上的負重才計入終生累積暴露的計算下，男性使用單次負重 3000 牛頓，女性 2800 牛頓，作為閾值的終生累積暴露值對 L4-S1 椎間盤突出有最好的預測度。針對腰椎後三節，椎間盤的高度、寬度與椎間盤突出具有相關性；比較以年齡、性別、身高、體重作為危險因子的預測方程式(Model 1)和再加入椎間盤的高度、寬度作為危險因子的預測方程式(Model 2)，發現後者的預測力較佳。

結論：

本研究顯示終生累積負重與椎間盤退化疾病之間具有劑量－效應關係，並定量出特定終生累積負重值對椎間盤退化的發生具有危險性；男性單次負重閾值 3000 牛頓，所計算的終生累積暴露值對 L4-S1 椎間盤突出有最好的預測度，女性為 2800 牛頓。以椎間盤的高度、寬度、年齡、性別、身高、體重等危險因子構成的預測方程式可以用來預測椎間盤突出的發生。本研究計算腰椎終生累積負重的模式與預測椎間盤突出之方程式可作為職場上累積負重暴露與預防疾病發生的參考。

關鍵字：

椎間盤退化性疾病、終生累積負重、椎間盤突出、閾值、橫斷性研究、腰椎核磁共振攝影、預測方程式

Abstract

Background and Objective: Lumbar disc degeneration (LDD) has been related to heavy physical loading. However, the quantification of the exposure has been controversial and the dose-response relationship with the LDD has not been established. It is also unclear whether a specific threshold value exists in each lifting load, the accumulation above which best predicts lumbar disc protrusion, or on the other hand, all lifting load should be accumulated. In a clinical setting, the radiographic diagnosis of disc condition typically requires magnetic resonance imaging (MRI), which is less readily available than plain radiograph is in most primary care facilities. If the relationship between reduced disc height and disc bulging or protrusion was existed, useful insight can be obtained to guide further direction of patient evaluation. The purposes of this study are to investigate the dose-response relationship between lifetime cumulative lifting load and LDD; to determine the optimal threshold value of lumbar compression load in each lifting, which allowed for best prediction for disc protrusion while lifetime cumulative load was calculated; and to determine the association between disc morphology and disc bulging or protrusion.

Method: This is a cross-sectional study. Every participant received assessments with a questionnaire, MRI of the lumbar spine and lumbar disc compression load. MRI assessments included disc dehydration, annulus tear, disc height narrowing, bulging, protrusion, extrusion, sequestration, degenerative and spondylolytic spondylolisthesis, foramina narrowing, and nerve root compression on each lumbar disc level. The compression load was predicted by a biomechanical software system. We sum up all lifting exposure to the calculation for examining the association between lifetime cumulative lifting load and LDD; and sum up only lifting load greater than proposed thresholds for determining the optimal threshold value of lumbar compression load in each lifting .For accumulation above different thresholds, predictive capabilities for disc protrusion were compared using four statistical values, (1) Area under the curve of a receiver operating characteristic curve, (2) R^2, (3) Akaike information criterion, and (4) Bayesian information criterion. The intervertebral disc height and disc depth were measured. Logistic regression analysis was applied to identify the association between anthropometric factors, disc morphology factors, and disc bulging/protrusion. Model 1 was constructed using anthropometric variables to investigate the capacity for predicting disc bulging/protrusion. Model 2 was constructed using anthropometric variables and disc morphology variables. The ability of the models to discriminate between participants with and without disc bulging/protrusion was evaluated using a receiver operating characteristic curve.

Result: A total of 553 participants were recruited in this study and categorized into tertiles by cumulative lifting load, i.e., $<4.0 \times 10^5$, 4.0×10^5–8.9×10^6, and $>= 8.9 \times 10^6$ Newton× hours. The risk of LDD increased with cumulative lifting load. The best dose-response relations was found at the L5–S1 disc level, in which high cumulative lifting load was associated with elevated odds ratios of 2.5 (95% CI 1.5–4.1) for dehydration, and 4.1(95% CI 1.9–10.1)for disc height narrowing comparing to low lifting load. Participants exposed to intermediate lifting load had increased odds ratios of 2.1(95% CI 1.3–3.3) for bulging comparing to low lifting load. The tests for trend were significant. For men, 3000 Newton for each lifting task was the optimal threshold value for predicting L4-S1 disc protrusion, whereas for women, 2800 Newton was optimal. Total of 452 MRI scans were analyzed for the morphology study. Age, body weight, body height, disc height, and disc depth were significantly associated with disc bulging/protrusion. The area-under-the-curve (AUC) statistics of Model 2 were significantly better than Model 1 at the L3-L4 (p<.05) and L4-L5 level (p<.05) but not at the L5-S1 level.

Conclusions: The results suggest a dose-response relationship between cumulative lifting load and LDD. Cumulative lifting load predicted L4-S1 disc protrusion best when the threshold value was set at 3000 Newton for men, and 2800 Newton for women. The results showed an association between disc morphology and disc bulging/protrusion at the L3-L4, L4-L5, and L5-S1 level. We also developed a model by using anthropometric factors and disc morphology to predict disc bulging/protrusion.

Key words: Lifetime cumulative lifting load; Lumbar disc degeneration; MRI; Dose-response relationship; disc morphology, disc protrusion; threshold value

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Chapter 1 Introduction

Lumbar disc degeneration (LDD) is associated with heavy physical loading [1-9]. Some individuals who experience degenerative changes in the discs may present with symptoms of low back pain (LBP) [6, 10, 11]. The substantial economic burden and productivity loss caused by LBP have become considerable societal problems. Comprehensive investigations of the lifetime cumulative load on lumbar discs that results in various LDD on each disc level are rarely conducted. Beside, only few studies have analyzed the dose-response relationship between physical loading and LDD. Establishing such a dose-response relationship is difficult because of suboptimal exposure assessments and a relative lack of definitive imaging findings regarding LDD. Therefore, understanding the dose-response relationship between physical loading and LDD can provide valuable information regarding safe lifting load for designing work tasks with relatively low risks of low back injury.

Among the disc degeneration conditions, herniated intervertebral disc (HIVD) is one of the most commonly diagnosed abnormalities associated low back pain and sciatica [12]. It has been listed as an occupational disease and compensated in many countries, such as Denmark, France, Germany, United States, and Taiwan

[7]. A crucial question is whether a specific threshold value exists in each lifting load, the accumulation above which best predicts HIVD, or on the other hand, all lifting load should be accumulated. A review of the literature revealed several recommended threshold lifting load values, but those might not be practicable for calculating the cumulative effects for several reasons. First, they were examined for a single spontaneous lift and the career-long effects of repeated lifting were not considered. Second, most of them were proposed for preventing low back pain, not for HIVD. Third, the current 3400N recommended values do not appear to be optimal because more than 50% of work-related low back injuries are attributed to tasks involving the manual handling of materials [13]. Fourth, uniform liftload limits are not generalizable across ethnicity and sex. Hence, it is essential to determine the optimal threshold value of liftload per lift for calculating the lifetime cumulative load in order to prevent HIVD in Taiwan.

Beside the risk factor of lifting load to disc herniation, we attempt to discover if there is association between disc morphology and disc protrusion. In the clinical setting, the radiographic diagnosis for disc herniation usually requires MRI, which is less readily available in most of the primary care facilities. Plain spine X-ray has difficulty providing information on disc conditions. Only reduction in disc height is visible in radiographs [14]. Since plain films are frequently obtained on patients with back pain, if the relationship could be established between reduced disc height and disc herniation, useful insight could be obtained to guide further directions of patient evaluation.

Accordingly, the purposes of this study were (1) to examine the dose-response relationship between lifetime cumulative lifting load and various LDD on each lumbar disc level; (2) to determine whether any threshold value existed to predict disc protrusion when calculating lifetime cumulative lifting load; and if so, what would have been the best threshold value; (3) to examine whether disc morphology can provide information useful for the prediction of disc bulging/protrusion, while controlling for anthropometric factors such as age, gender, body height, and body weight, which have been associated with LDD or disc herniation [15-20]. Furthermore, if such relationship is present, this study also aims to establish a predicting model using anthropometric factors and disc morphology to predict disc bulging/protrusion.

Chapter 2 Literature Review

A. Epidemiology of Low Back Pain and Intervertebral Disc Degeneration

Low back pain is a major public health problem in western industrialized societies. According to a systematic literature review of population prevalence studies of low back pain between 1966 and 1998, the point prevalence ranged from 12% to 33%, 1-year prevalence ranged from 22% to 65%, and lifetime prevalence ranged from 11% to 84% [21]. It also places an enormous economic burden on society; its total cost, including direct medical costs, insurance, lost production and disability benefits, is estimated at £12 billion per annum in the UK and 1.7% of the gross national product in the Netherlands[22, 23]. Back pain is apparent the most prevalent and costly musculoskeletal disorders (MSDs) among United State (U.S.) industries. The total cost was estimated to be 50~100 billion in 1990. It also accounted one forth of the workers’ compensation claims and one third of the compensation costs[24]. According to the U.S. Bureau of Labor Statistics, 11 to 13 million people developed LBP in 2000, and approximately $100 billion were spent on treating this symptom [25]. A nationwide study in Taiwan reported prevalence of low back and waist pain to be 18.3% in male workers and 19.7% in female workers [26]. According to the National Health Insurance Bureau report, more than 2.14 million patients sought medical care for back pain in 1998. The medical cost exceeded 3 billion New Taiwan Dollars. The direct and indirect cost associated with low back pain is tremendous.

Low back pain may arise from a spectrum of conditions, e.g. strain and sprain, osteoarthritis, degenerative disc disease, inflammatory spondylitis etc. Disc degeneration of the lumbar spine is considered as one of the underlying factors of LBP, but controversy still prevails about the relationship. In some magnetic resonance imaging (MRI) studies an association has been found [11, 27-29] although degenerative changes have been found to be common in asymptomatic people as well [29, 30]. Luoma found an increased risk of LBP was found in relation to disc dehydration and disc bulge[28]. In a meta-analysis study, Endean found disc protrusion, nerve root compression, disc dehydration and annulus tear were associated with LBP [11]. Among disc degeneration conditions, herniated nucleus pulpolus, or herniated intervertebral disc (HIVD) is one of the most commonly diagnosed abnormalities associated low back pain and sciatica [12]. Disc protrusion has been listed as an occupational disease and compensated in many countries, such as Denmark, France, Germany, United States, and Taiwan [2].

B. Risk Factor of Intervertebral Disc Degeneration

I. Definition of Intervertebral Disc Degeneration

Studies had pointed to there are two main challenges in epidemiology related to disc degeneration [5, 31]. First, there is no standard definition of disc degeneration, thus the systems of measurement vary between studies and lead to complicate comparisons. Second, measures of disc degeneration often lack adequate reliability and precision. Definitions have not been uniform, to some extent because the phenomenon is not well understood. Disc degeneration is a product of lifelong degradation with synchronized remodeling of discs and neighboring vertebrae, including simultaneous adaptation of the disc structures to changes in physical loading and responses to the occasional injury. Generally, disc degeneration is defined largely by the method of evaluation. For large population samples, the currently preferred method of evaluation is magnetic resonance imaging.

II. Prevalence of Disc Degeneration

Reported prevalences vary widely between samples and studies. The range of reported prevalences for asymptomatic subjects was as follows: 10% to 81% for bulging, 3% to 63% for protrusion, 0% to 24% for extrusion, 20% to 83% for reduction in signal intensity, 3% to 56% for disc narrowing, and 6% to 56% for anular tears. Prevalences for subjects not selected of absence of back pain were as follows: 22% to 48% for bulging, 0% to 79% for protrusion, 1% to 55% for extrusion, 0% sequestration, 9% to 86% for reduction in signal intensity, 15% to 53% for disc narrowing, and 15% for anular tears [5]. Differences between studies in subjects' age, disc levels and exposure to risk factors may have contributed to the variations in prevalence rates reported.

III. Anthropometric Factors to Disc Degeneration

The mechanisms for the degenerative changes in the disc are poorly understood, but aging is the biggest determinant. There have been many epidemiological studies over the past 30 years [5, 18-20, 29, 32]. In Battié's study [5], it showed that various degenerative findings were associated with increasing age from thirty-five to seventy years among 116 men. Videman had indicated LDD including disc dehydration, bulge and disc height narrowing show an increasing prevalence with increasing age [18]. Another study reported that increasing age correlated with a higher prevalence of disc bulge [20]. Twomey showed the intervertebral disc become more convex in the old age [32]. In a review article, Miller *et al* reported an increase in disc degeneration from 16% at age 20 to about 98% at age 70 years based on macroscopic disc degeneration grades of 600 autopsy specimens [19]. Age is found to be strongly associated with lumbar disc degeneration.

With respect to gender, men was found degenerative changes earlier than in women by approximately ten years [31]. Miller *et al* reported that lumbar disc degeneration appeared already in 11- to 19-year-old males and 10 years later in females [19]. An epidemiologic case-control study to identify risk factors for acute prolapsed lumbar intervertebral disc showed that the ratio of men to women was 1.5 to 1 among surgical cases [33]. Some studies have indicated that tallness is a factor associated with an increased risk of herniation [15, 17], but Kelsey’s studies failed to support such relationship [33, 34]. In Hrubec’s results, he reported body height and body weight were positively associated with the risk of disc herniation diagnosed in United States Army hospital [15]. In a study on disc herniation, men with a height of 180 cm or more showed a relative risk of 2.3 and women with a height of 170 cm or more 3.7, compared with those who were more than 10 cm shorter. The author reported that body height may be an important contributors to the herniation of lumbar intervertebral disc [17].

The only chemical exposure associated with disc degeneration is cigarette smoking. In kelsey’ study, cigarette smoking in the past year was associated with an increased risk for prolapsed disc [33]. Cigarette smoking was reported that only explain 2% of the variance in disc degeneration from lumbar magnetic resonance images when studying monozygotic twin siblings who were highly exposed to a lifetime smoking history (32 pack-years in mean) [35]. In another study of monozygotic twins study, no significant association between disc degeneration and smoking was found [6].

IV. Disc Morphology Factors to Disc Degeneration

Several studies have showed that disc morphology changes were observed in disc degeneration. In some cases, the degree of disc degeneration has been commonly assessed by the disc height decrease rather than by signal intensity change in the nucleus pulposus on MRI [36]. It has long been clinical experience that patients with disc bulging or protrusion have disc space narrowing [37]. Degeneration of the intervertebral disc is associated with progressive changes in disc morphology, matrix composition and properties [14]. The decrease in the intervertebral disc space would constrict the intervertebral foramen sufficiently to cause entrapment or compression of the spinal nerve root. A 1 mm narrowing of the intervertebral disc space was reported to correspond to a reduction of 20–30% in the foraminal area [38]. Tibrewal showed that patients with disc herniation had reduced disc height compared with the normal although the differences did not reach statistical significance [37]. The reason might be because of the smaller samples size in this study and the greater anatomic variation at the L5-S1 disc level. Brinckmann and Grootenboer found a disc height reduction and an increase in disc bulge occur in proportion to the amount of disc tissue removed [39]. In another study, the authors found fracture and discectomy result in an increase of the radial disc bulge and a decrease of the disc height [40]. These studies revealed that there was a relation between disc height and disc bulge. According to Natarajan’s study, it suggested that changes in disc volume or disc area might be more rational to disc bulging than decrease of disc height [41].

Several studies had reported that disc height or disc depth was related to age [18, 32, 41-44]. Natarajan found there is a decline of disc height after the fifth decade of life [41]. Amonookuofi showed that disc height and diameter vary significantly in the different age groups [42]. The sizes of disc increase as a person age [42]. Age and axial disc size were reported account for more of the explained variance (6%) in disc height narrowing [16]. In another study, the maximum disc height was greater in the older (50-60 years) than in the younger individuals (20-30 years)

[44]. It was presumed to be a result of the microfracture of the endplate during adult life, which leads to a more concave form of the intervertebral disc [44]. However, Koeller had different observation that the average disc height is almost independent of age [45]. The height of the intervertebral disc is influenced by several factors. Age and the grade of disc degeneration also influence the disc height. Both factors are related, as the incidence and degree of disc degeneration increase considerably with age [46].

V. Genetics Factors to Disc Degeneration

In recent years, a dramatic advance has been shifted to the genetic influences on the risk for disc degeneration. In one review article, Ala-Kokko noted that environmental factors may explain only a small portion of disc degeneration and concluded that “genetic factors play an important role in disc pathology [degeneration], and perhaps a major one”[47]. Two of the first systematic analyses of familial aggregation of disc degeneration were conducted with monozygotic twin pairs [6, 48]. Results from these studies demonstrated substantial familial aggregation in terms of the extent and location of disc degeneration. One of the studies assessed the degree of similarities in degenerative findings by spinal level in the lumbar discs of 20 pairs of monozygotic twins from 36 to 60 years of age, relative to what would be expected by chance based on the prevalence of the findings by level among all 40 subjects [48]. Results suggested a substantial familial influence on degenerative findings studied in the spine. Furthermore, in the other study published in 1995, lumbar MRIs of 115 pairs of male MZ twins were assessed to investigate the relative effects of environmental exposures commonly suspected as risk factors for disc degeneration, age and familial aggregation on disc bulging and disc height narrowing [6]. In a multivariable analysis of the T12–L4 region, physical loading exposures explained 7% of the variance in summary disc degeneration scores among the 230 subjects; this rose to 16% with the addition of age and to 77% with the addition of a variable representing familial aggregation. In the L4–L5 and L5-S1 region, physical loading measures explained only 2% of the variance in disc degeneration summary scores in multivariable analysis. The portion of the variance in lower-lumbar disc degeneration scores explained rose to 9% with the addition of age and to 43% with the addition of familial aggregation. Significantly more of the variance in degeneration remained unexplained in the lower lumbar region, as compared to the upper lumbar region, and is likely the result of mechanical forces interacting with spinal anthropometrics in such a way as to have a disproportional effect on the lower lumbar levels. This study provided the first estimate of the relative importance of specific environmental agents and overall familial influences, which include genetic factors [48].

VI. Occupational Exposure and Disc Degeneration

Previous studies had shown the relation between lumbar disc degeneration and occupational risk factors such as heavy lifting, forward bending, awkward posture and whole body vibration, particularly heavy physical loading have been the main suspected risk factors [1-9]. The association of mechanical load on spinal structures and back pain has been reported [34, 49-51]. The L4-S1 lumbar discs usually have the highest prevalence of disc degeneration than L1-L4 discs, suggesting the role of lifetimes physical exposure in disc pathogenesis because aging and genetic effect could be expected to affect all discs similarly [6]. The traditional view as to the causes of the disc degeneration was as the result of "wear and tear" on the disc from daily exposures to physical loading or biomechanical forces [31]. During loading the disc deforms and loses height gradually. As the disc changes its composition because of ageing or degeneration, the response of the disc to mechanical loads also changes. With a loss of proteoglycan and thus water content, the nucleus can no longer respond as efficiently. This change results in uneven stresses across the endplate and the annulus fibres, and, in severe cases of degeneration, the inner fibres may bulge inward when the disc is loaded. It may lead to abnormal stresses on other disc structures, eventually causing more severe condition. Disc height narrowing affects other spinal structures, such as muscles and ligaments, and, in particular, leads to an increase in pressure on the facet joints, which may be the cause of the degenerative changes seen in the facet joints of spines with abnormal discs [45]. With respect to whole-body vibration or driving, a case-control study found the greater the number of hours spent in a motor vehicle, the higher the risk of having disc protrusion [33]. A study of forty-five pairs of monozygotic twins who were highly exposed to motorized vehicles and associated whole-body vibration did not find an association between lumbar disc degeneration and lifetime driving histories. The current evidence suggests no notable effect of driving on disc degeneration [6] .

C. Dose-Response Relationship between Cumulative Lifting Load and Disc Degeneration

In the cumulative or repetitive injury model of intervertebral disc degeneration, physical loading or biomechanical forces on the discs, particularly through occupational physical demands, have been the main suspected risk factors [52, 53] . Cumulative loading can be defined as one of the following: the accumulated demands on the spine during the duration of activity; loads build up over the period of a work shift; or the accumulation of loading throughout a worker’s lifetime [54]. Numerous studies had documented the association between cumulative spinal load and low back injuries [54-58]. Based on an “injury”' paradigm model, it implies that overloading results in structural damage which leads to disc degeneration causing symptomatic conditions. This model did not examine the biological capacity of the musculoskeletal system to adapt to external exposures. Biological tissues are viscoelastic in nature, and prolonged loads may results in cumulative fatigue, which reduces their stress-bearing capacity. Such changes may reduce the threshold stress which the tissue fail. It is considerable that the history of exposure to physical load may decrease the threshold for precipitation of back injuries or disc degeneration, as well as the peak load at which the injuries precipitate [58].

In spite of significant association between certain occupational exposures and intervertebral disc disease, a threshold for occupational exposure or a dose-response relationship have not been established. Only few studies have shown a dose-response relationship between physical workload and lumbar disc degeneration. Kelsey’s study indicated that subjects lifting objects more than 11.3 kg (25 lb) over 25 times per day had more than three times the risk for acute prolapsed lumbar intervertebral disc compare to persons without lifting [7]. Hofmann revealed an association between length of employment in nurses with high spinal load and the risk of disc herniation. Seilder showed a postive dose-response relation between cumulative lumbar load and lumbar disc herniation (through manual materials handling and/or intensive load postures) [1-3]. The odds ratio (OR) of herniation for men with a sum of exposure of

>21.51 $\times 10^6$ Nh verse subjects with a sum of up to 5.0 $\times 10^6$ Nh was 3.4 [3].

D. Threshold Value of Lifting Load to Disc Degeneration

Threshold value is considered the value above which the risk or probability of injury increases significantly. It is necessary to judge the amount of load required by the work. Information on the back force requirements of the work can be used to plan and assess interventions to decrease the number of work-related injuries.

A review of the literature revealed several recommended threshold liftload values, although most of them were used in the prevention of low back injury [54, 55, 59-64]. Chaffin and Park found low back injury incidence rates of 5% and 10% among workers (n = 411) when the estimated compressive force at L5/S1 was higher than respectively 2500 N and 4500 N [62]. For jobs with predicted compressive force at L5/S1 between 4500 N and 6800 N, the authors found a rate of back injuries more than 1.5 times higher than for jobs with predicted compressive force lower than 4500 N [65]. The National Institute for Occupational Safety and Health (NIOSH) suggested that if spinal compression exceeds approximately 3400 N, workers would be at an increased risk of low back injury [66]. NIOSH guidelines for compression are based on the studies of Evans and

Sonoda [67]. The results of these studies show that even though the intervertebral discs do not rupture, microfractures of the vertebral cartilage endplates of cadavers of subjects under 40 years old start to happen when applying on average 6700 N of axial load (1500 pounds, approximately 680 Kg). When the spines were from subjects 60 or more years old, the microfractures started to happen when applying average axial loads of 3400 N [67]. The major limitation of NIOSH 1981 guidelines is that the cutpoints are based on cadaver studies with large standard deviations, and the living structures threshold to compression injury for different people might differ. Even NIOSH questions the value of 3400 N, NIOSH opinion is that this value “may not protect the entire workforce” [65]. In addition, the guidelines are based on studies of axial compression only and do not take into account the cumulative effect and temporal characteristics of the exertions over time on the viscoelastic tissues of the body [58]. The compression guidelines proposed by NIOSH are widely used, however, as suggested by different studies, they are probably inaccurate and when followed may expose the workforce to demands exceeding its capacity.

Norman et al studied more than 10,000 automotive assembly workers [55]. When the authors compared a sub-group of 104 cases (with low back injury) with 130 controls (without low back injury) the peak shear force on L4/L5 (odds ratio of 2.3) emerged as the strongest factor followed by peak compression force on L4/L5 (odds ratio of 1.9). The mean peak compression load of the auto-assembly workers who reported low back pain was 3423 N. This value was statistically different ($p < 0.001$) form the mean value found for the group who did not report low back pain (2733 N). Jager and Luttman compared the results from their proposed biomechanical model for low back axial compression with the literature regarding lumbar compression strength [60]. The average ultimate axial compression strength (total of 307 lumbar segments) reported by the authors was 4400 N (standard deviation 1900).

Only few studies of threshold value to disc protrusion were reported. Hutton and Adams found a mean value of 10249 N as being representative of the ultimate compressive axial force of intervertebral discs of cadavers of males between 22 and 46 years old [63]. They found that more than 40% of the intervertebral disks prolapsed when 5400 N of axial load was applied to flexed spines (simulated by wedging vertebral bodies)[63]. Additionally, in another study the authors observed trabecular fractures in the intervertebral discs when an average repetitive axial load of 3800 N was applied to simulated hyperflexed spines [59]. However, the reference values being used to-date do not seem to be optimally effective. Evidence of this inadequacy is given by the low success achieved so far in controlling work-related low back injures.

E. Exposure Assessment Methods

I. Exposure assessment methods

It has been proposed that mechanical exposure during physical work should be described by three main dimensions: (1) Intensity —intensity of the force, (2) Repetitiveness—the frequency of shifts between force levels and (3) Duration—the time the physical activity is performed. Any attempt to quantify exposure should include all the three dimensions for a worker being assessed. A wide range of exposure assessment methods has been identified and categorized as self-reports, observational methods and direct measurements [68]. Self-reports from workers such as interviews and questionnaires can be used to collect demographic data, occupational data on workplace exposure. A major problem with these methods is that worker perceptions of exposure have been found to be imprecise and unreliable. Direct measures such as laboratory methods used motion analysis systems, electromyography and accelerometry to achieve comprehensive information, but they could not be generalized to worksites and were limited to small sample sizes. They are more costly and require greater effort by participants and researchers. However, the validity and reliability in measuring mechanical exposure are increased [50].

II. Three-Dimensional Static Strength Prediction Program (3D SSPP)

Numerous methods have been developed for estimating the disc compression load. Direct measurement of lumbar spine load through *in vivo* studies is rare because of concerning about the ethical issue that it should implant a transducer or sensor into the disc. The first intradiscal pressure data was reported by Nachemson during the 1960s and was the important reference for rehabilitation medicine and workplace recommendations [69]. In 1998, Hans-Joachim conducted another intradiscal pressure measurement with one volunteer performing various activities and found good correlation with Nachemson’s data [70]. However, this type of study is rarely attempted because of the ethical considerations regarding such an invasive procedure. Presently it is not feasible to directly monitor the loads imposed on the spine structure and tissues while workers are performing an occupationally related task in the workplace. Instead, indirect measures such as computerized biomechanical modeling is considered the most precise method and typically used for estimating the disc compression load. The Three-Dimensional Static Strength Prediction Program (3D SSPP) was a biomechanical model developed by the

Center for Ergonomics at the University of Michigan. This program is normally applicable to the analysis of “slow” movements used in heavy material handling tasks since the biomechanical computations assume that the effects of acceleration and momentum are negligible. However, it accounts for internal and external forces occurring in and on the body. The subjects’ anthropometric data were part of the U.S. industrial database used by the University of Michigan Center for Ergonomics to develop the 3D SSPP software [71]. Jang conducted a field study to investigate spinal compression force of nursing tasks in a hospital setting by utilizing 3D SSPP [51].The results showed consistency with Marras’s laboratory based study by using the EMG-assisted model [72]. The 3D SSPP was further utilized as a gold standard to the HCBCF (Hand-calculated back compress force) estimation model for ergonomic evaluation of 600 lifting tasks [73]. The 3DSSPP was also used as a measurement tool in several studies [74]. Among the measurement methods, 3-dimention Static Strength Prediction Program (3D SSPP, Center for Ergonomics, University of Michigan) software system was considered a more quantitative tool to estimate spinal load.

Chapter 3 Material and Method

Part I. Dose-Response Relationship between Lumbar Disc Degeneration and Life Time Cumulative Lifting Load

Study Population

We conducted a cross-sectional study. To analyze workers from a broad spectrum of lifting exposures, the participants in this study were recruited from 2 populations. The group that carried heavy load comprised members of the San Chung Fruit and Vegetable Wholesale Market in Taiwan. Most of these workers load and unload fruit boxes almost every day; thus, lifting is a common task at their workplace. Patients who sought treatment in the Internal Medicine Clinic of the National Taiwan University Hospital (NTUH) and were diagnosed with upper respiratory infections (URI), mostly the common cold, were recruited as the background population. During recruitment, the wholesale market workers and the walk-in clinic patients were not informed of the hypothesis of the study. They were invited to participate in a survey regarding spine and bone disorders. The inclusion criteria for the study were an age between 20–65 years and at least 6 months of working experience. A person was excluded if he or she had been previously diagnosed with cancer, psychiatric conditions, spinal tumors, inflammatory spondylopathy, compression fracture, or major back trauma. We pooled these 2 populations to examine the effects of lifting on LDD, and the entire population was categorized into tertiles according to lumbar cumulative lifting load. Figure1 shows the participant selection process implemented in this study. 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 consent forms. The study protocols were reviewed and approved by the Institutional Review Board of the NTUH.

Data Collection

Every participant was assessed by using a questionnaire and obtaining MRI images of the lumbar spine. The demographic and occupational data of the participants were obtained from the extensive, structured questionnaire. For each participant, a complete occupational history and a history of back pain as well as information on job tasks, driving and riding experience, leisure activities, drinking, and smoking were collected. The participants reviewed each job held since they entered the workforce. The requested information included job titles, working tenures, body weights at each job, descriptions of tasks, lifting exposure at work (such as estimates of the most common weights lifted or carried), the frequency and duration of lifting or carrying, the number of working hours per day, and the number of working days per week. A structured interview was implemented to provide the participants with adequate time for assessing the relevant work tasks in each job in their occupational history. The trained interviewers used common milestones in life to help the participants recall the necessary information. 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. Cigarette exposure was calculated in pack-years by multiplying the number of packs of cigarettes smoked daily by the number of smoking years.

Estimation of Lifetime Compression Load on Lumbar Disc

Regarding the estimation of lifetime compression load, the participants recalled all of the jobs that they held after completing schooling. When a person performs a lifting task, the compression load on the spinal disc is increased. Therefore, work tasks involving the manual materials handling were used to represent the compression load for each job. Specific objects that had been lifted or carried regularly were described, and participants subsequently answered questions concerning 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 frontal and lateral views of each lifting posture were photographed according to a standardized photography procedure work sheet. To generalize the compression load into the cumulative lifting exposure in Newton × hours (Nh), the following method was used for representing the compression load of each job. A participant was instructed to choose an empty box of a size similar to those of objects typically carried at work. Bottles of water were placed in the box until the total weight was similar to those of the typical objects, and the resulting weight was used as an estimate of the typical weight carried for that specific job. Subsequently, the participant was instructed to demonstrate simulated working postures, including lift-up, transferring, and unloading postures, by using the empty box, and photographs of these postures were captured. 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 lifting positions 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 lumbar disc during lifting was estimated using the 3 Dimension Static Strength Prediction Program (3DSSPP, Center for Ergonomics, University of Michigan) software system [51, 73]. The 3DSSPP was used to predict the static strength requirements for tasks such as lifts, pushes, and pulls during each work period. Anthropometric data such as the gender, height, body weight, carried load, and working posture photograph of each participant were input into the 3DSSPP system to predict the compression load on the lumbar disc. In addition, the angle of the body can be adjusted automatically by using the system. To evaluate the intra-rater and inter-rater reliability of lumbar load estimation by using the 3DSSPP, photos of the simulated work conditions of the 60 study participants were repeatedly evaluated in 2 rounds, and the second round of evaluation was conducted 4 weeks after the first.

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 force ($F_{\text{lift-up}}$) and lift-up time ($t_{\text{lift-up}}$), transporting force ($F_{\text{transporting}}$) and transporting time ($t_{\text{transporting}}$), and unloading force (F_{unload}) and unloading time (t_{unload}). The cumulative compression load calculation method used in this study was modified from that used by Seidler [1-3]. However, unlike Seidler, we used the 3DSSPP to estimate the lumbar compression load. For each job described, the load on the lumbar disc was calculated as the product of the compression load and the duration of lifting in hours. The lifetime cumulative load (Nh) for each participant was then estimated by summing the loads on the lumbar disc from all jobs. The calculation can be expressed as the following equation:

Cumulative lifting load =

$$\sum [(F_{\text{lift-up}} * t_{\text{lift-up}} + F_{\text{transporting}} * t_{\text{transporting}} + F_{\text{unload}} * t_{\text{unload}})/3600 * \text{frequency of lifting/day} * \text{working days/year} * \text{working year}]$$

F: compression load on the lumbar disc

t: time (second)

According to the findings of Siedler, all workloads from the past contribute to LDD [3]. Therefore, the lifetime cumulative load for each participant was estimated by summing each load on the lumbar disc from all jobs. In previous studies, the lifetime exposure was typically estimated using the number of working hours per day [1-3]. However, in practical working environments, workers do not lift for 8 hours daily; therefore, the results might have been overestimated in previous studies. By contrast, the detailed investigation and calculation methods used in this study were implemented for calculating precise cumulative lifting exposure values.

The researchers visited the fruit market to obtain a video recording of the working conditions and lifting processes, and observed that the weight lifted per unit of fruit was rather regular, thus simplifying the calculation process. The video recording was rated separately by using the 3DSSPP, which yielded results consistent with those from the recollections of the fruit market workers. The reproducibility of the lifting measurements was tested 6 months after the initial interview with the help of 25 participants. The lifting measurements of their current jobs were used for reliability testing. These measurements included the weight lifted, lift-up time, frequency of lifting per day, and tenure at the job. We observed 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 and unloading time were not examined. After observing and recording the fruit workers’ practices, 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 compression load of pushing and pulling were not assessed.

Magnetic Resonance Imaging Equipment and Protocol

The LDD was assessed using MRI. All MRI examinations were obtained at the NTUH by using a GE 1.5-T unit (General Electric Medical Systems, Milwaukee, WI) and a spine array coil (5 × 11 in.). The study involved 4 spin-echo sequences: an axial localizer (spoiled gradient), sagittal views with a repetition time and echo time (TR/TE) of 500/minimum full ms and 3350/110 ms, and an axial view with a TR/TE of 5325/110 ms. The slice thickness was 4 mm for sagittal and axial sequences, and the field of view was 28 and 20 cm for the sagittal and axial images, respectively. The T1-weighted axial sequences were stacked slices extending from the inferior aspect of T12 through the inferior aspect of S1. The T1-weighted axial and sagittal images exhibited 2 excitations, and the T2-weighted sagittal images exhibited one excitation.

Definition of the Degenerative Disc Related Magnetic Resonance Imaging Findings

Each intervertebral disc from L1–L2 to L5–S1 was evaluated for disc dehydration, annulus tear, disc height narrowing, disc bulging, protrusion, extrusion, sequestration, degenerative and spondylolytic spondylolisthesis, foramina narrowing, and nerve root compression. An experienced radiologist performed the evaluation based on standard images and according to written instructions. The radiologist was blinded to the participants’ medical histories and occupational exposure statuses. Disc dehydration was defined as T2-weighted signal intensity loss from the intervertebral disc [75]. Annular tears are separations between annular fibers, the avulsion of fibers from their vertebral body insertions, or breaks through fibers that extend radially, transversely, or concentrically, involving one or more layers of the annular lamellae [76]. According to the Farfan method [77], disc height can be measured as the mean of the ventral and dorsal distances between the contours of the adjacent vertebral bodies. Reduction of disc height was defined as a disc narrower than the upper disc that it was normal [20]. Disc bulging was defined as the presence of disc tissue that is circumferentially (50%–100%) beyond the edges of the ring apophyses. Protrusion was present if the greatest distance, in any plane, between the edges of the disc material beyond the disc space was more than the distance between the edges of the base in the same plane. Extrusion was present when, in at least one plane, any one distance between the edges of the disc material beyond the disc space was greater than the distance between the edges of the base, or when no continuity existed between the disc material beyond the disc space and that within the disc space. Extrusion may be further specified as sequestration if the displaced disc material has completely lost continuity with the parent disc [76]. Spondylolytic spondylolisthesis was identified in a lateral projection as an anterior displacement with a break of the pars interarticularis. Degenerative spondylolisthesis was defined as with an intact pars interarticularis, and spondylolytic spondylolisthesis involves the separation of the posterior aspect of the vertebral body from the anterior body [75]. The intrareader reliability regarding the presence or absence of each MRI variable was determined as the average reliability of 5 lumbar discs of the 60 participants evaluated on 2 occasions within 3 months.

Statistical Analysis

All statistical analyses were conducted using JMP 5.0 (SAS Company). For the evaluation of the occurrence of LDD among the lifting group, a logistic regression was conducted, adjusting for potential risk factors including age, gender, body mass index (BMI), and smoking. To calculate trend analyze, the lifting exposure was included as interval-scaled variables in the logistic regression model. Power calculation in this study that with alpha error of 0.05, twice the risk compared with the reference group, a prevalence <3.5% in degenerative-disc-related MRI findings in each lifting load group (data not shown) could not achieve statistical power of 80%. Therefore, we did not further examine the relationship between the lifting exposure and these MRI variables (prevalence <3.5%). A Bonferroni correction for multiple comparisons was performed, and *P* values <.0042 and <.0083 indicated significance for the upper and lower lumbar region, respectively. The reproducibilities of the modified calculation of the compression load and lifting measurements were analyzed by using SPSS (16.0 for Windows) to compute intraclass correlation coefficients (ICC). Percentage agreement was used to assess the intrareader reliability of the MRI variables.

Part II. Threshold Values of Lumbar Load in Lifting for Calculating Lifetime Cumulative Load to Predict Disc Protrusion

Study Population

This study is a further investigation of the previous study. Recruitment of the participants, measurements of the work exposure, and imaging studies of the lumbar spines were detailed in part I. To obtain a broad spectrum of lifting exposures, the participants were recruited from 2 populations: (1) walk-in clinic patients and (2) workers who carry heavy loads. Patients visited the Internal Medicine Clinic of one National 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 of one fruit and vegetable wholesale market. Lifting is a common task for these workers. During recruitment, the market workers and the walk-in clinic patients were not informed of the hypothesis of the study. They were invited to participate in a study regarding spine and bone disorders. The inclusion criteria of this study were between 20 and 65 years and at least 6 months of working experience. Participants previously diagnosed with compression fracture, major back trauma, inflammatory spondylopathy, spinal tumors, cancer, or psychiatric conditions were excluded. We combined these 2 populations to examine the effects of lifting on disc protrusion.

Data Collection

Each participant was asked to complete a questionnaire and to obtain MRI of the lumbar spine. The demographic and occupational data were obtained from an extensive, structured questionnaire. A detailed structured interview with adequate time was implemented to the participants for assessing the relevant work tasks in each job held since they entered the workforce including a complete occupational history, job titles, working tenures, body weights at each job, descriptions of tasks, lifting exposure at work (eg, estimates of the most common weights lifted), frequency and duration of lifting, numbers of working hours per day and working days per week. The trained interviewers used common milestones in life to help the participants recall the necessary information. 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. Cigarette exposure was calculated in pack-years by multiplying the number of packs of cigarettes smoked daily by the number of smoking years.

Estimation of Lumbar Disc Compression Load and Calculation of Lifetime Cumulative Lifting Load on the Lumbar Disc

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 lumbar disc during lifting was estimated using the 3D Static Strength Prediction Program (3DSSPP, Center for Ergonomics, University of Michigan, Ann Arbor, Michigan) software system . Anthropometric data such as sex, height, body weight, carried weight, and working posture photograph of each participant were input into the 3DSSPP system to predict the compression load on the lumbar disc. To evaluate the intrarater and interrater reliability of lumbar load estimation by using the 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.

To investigate the actual cumulative lifting exposure, the participants recalled details regarding lift-up time ($t_{lift\text{-}up}$), transporting time ($t_{transporting}$), 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 force ($F_{lift\text{-}up}$) and lift-up time, transporting force ($F_{transporting}$) and transporting time, and unloading force (F_{unload}) and unloading time. Only those lift-up forces greater than proposed threshold value were added into lifetime exposure. For each job described, the lifting exposure was calculated as the product of the lifting load and the duration of lifting in hours (Newton × hour, Nh). The lifetime cumulative load for each participant was then calculated by summing the lifting exposure on the lumbar disc from all jobs.

Threshold Value of Lifting Load

The threshold value in this study was defined as exposure with a lifting load above this proposed value was considered as contributed to disc protrusion over an entire career life, and was included in the lifetime cumulative calculation. The proposed threshold values were set at zero Newton (N), and at 100 N increments from 2000 to 4000 N. For example, if the threshold value is set as 3400 N, only lifting load above 3400 N per lift will be included in the calculation. And, when the threshold value is set at 0 N, every lifting load generated from each activity will be included in the calculation. The calculation can be expressed as the following equation:

Cumulative lifting load =

$$\sum [(F_{\text{lift-up}}*t_{\text{lift-up}} + F_{\text{transporting}}*t_{\text{transporting}} + F_{\text{unload}}*t_{\text{unload}})/3600 * \text{frequency of lifting/day} * \text{working days/year} * \text{working year}]$$

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

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 disc at L4–L5 to L5–S1 was evaluated for disc bulging, protrusion, extrusion, and sequestration using MRI. All MRI examinations were conducted at the National University Hospital. MRI equipment and protocol, definition of disc condition above, the evaluation of intrarater reliability regarding the presence or absence of disc conditions were descripted previously.

Statistical 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 disc protrusion. 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 disc protrusion at either of the lower disc levels, namely, L4-L5 and L5-S1 disc, adjusting for potential risk factors including age, body mass index (BMI), and smoking. $P < 0.05$ was considered to be statistically significant. To determine the best threshold value of lifting load, four statistical values were used to compare outcome (L4-S1disc 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) 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.

Part III. Prediction of Lumbar Disc Bulging or Protrusion Based on Anthropometric Factors and Disc Morphology

Subject and Data Collection

This study is a part of the first study. We retrospectively reviewed the 553 participants' MRI scans in this study. Every participant received assessment with a questionnaire and MRI of the lumbar spine. The participants were between 20-65 years of age. Before participating in the study, they received written and oral information regarding the study procedures and potential adverse effects, and signed informed consent forms. The study protocols were reviewed and approved by the Institutional Review Board of the National Taiwan University Hospital (NTUH). Those with spondylolisthesis and/or lumbar spine operation were excluded from this study, due to potential inaccuracy in the measurements of disc height and disc depth, anteroposterior diameter of the intervertebral disc. All MRI examinations were obtained at NTUH. The equipment and protocol were detail described in part I.

Definition of Disc Bulging and Protrusion

Intervertebral disc at L3-L4, L4-L5, and L5-S1 level was evaluated for disc bulging and protrusion. These levels were investigated in this study as degeneration occurred most often and earlier in three lower levels [19, 78]. An experienced radiologist performed the evaluation based on standard images and according to written instructions. The radiologist was blinded to the participants' medical histories and occupational exposure statuses. Disc bulging was defined as the presence of disc tissue that is circumferentially (50%–100%) beyond the edges of the ring apophyses. Protrusion was defined as if the greatest distance, in any plane, between the edges of the disc material beyond the disc space was more than the distance between the edges of the base in the same plane [79]. The intra-rater reliability regarding the presence or absence of disc bulging/protrusion was determined as 60 participants evaluated on 2 occasions within 3 months.

Disc Morphology Measurement

There have been numerous reports of measurements of the lumbar disc height and disc depth [37, 42, 77, 80, 81]. Based on the previous studies, we calculated disc height as the mean of the anterior and posterior disc heights, and disc depth as the mean of superior and inferior disc depth. The disc morphology measurements were based on bony structure, but not the observed disc. This allows for future development of prediction methods using plain films. For L3-L4 disc, L4-L5 disc, L5-S1 disc, these measurements were carried out by two investigators, as follows: (1) Anterior disc height (ADH) was measured from the anterior corners of the adjacent superior and inferior vertebral bodies.

(2) Posterior disc height (PDH) was measured from the posterior corners of the adjacent superior and inferior vertebral bodies.

(3)The disc height (DH) was calculated as the mean of ADH and PDH, using the method with reference to Dabbs' measurement [80].

(4) Superior disc depth (SDD) was measured as inferior distance between anterior to posterior corners of the upper vertebral body.

(5) Inferior disc depth (IDD) was measured as superior distance between anterior to posterior corners of the lower vertebral body.

(6) Disc depth (DD) or anteroposterior diameter of intervertebral disc, was taken as the mean of the SDD and IDD [37, 42, 77].

The lines providing the DD and DH measures were drawn by the computer based on a standard algorithm. DD and DH measurements were performed three times in a subgroup of 57 subjects by two readers. One reader performed two measurements at 14 days interval, allowing calculation of intra-rater reliability. The results of the second reader were compared with the mean result of DD and DH measurements of the first, so inter-rater reliability could be ascertained.

Statistical Analysis

All statistical analyses were performed with statistical software JMP version 5.0 (SAS Company). Categorical variables are expressed as frequency and percentage, continuous variables as mean and standard deviation (SD). Percentage agreement was used to evaluate MRI reproducibility of disc bulging/protrusion. The reliabilities of digitizing procedures within examiners at a 2-week interval and between examiners were assessed with intraclass correlation coefficient (ICC). Logistic regression analysis was applied to identify the association between anthropometric factors, disc morphology factors and disc bulging/protrusion at L3-L4, L4-L5, and L5-S1 levels. $P < 0.05$ was considered to be statistically significant. The ability of the models to discriminate between participants with and without disc bulging/protrusion was evaluated by receiver operating characteristic (ROC) curve. Models with area-under-the-curve (AUC) statistics equal to 0.5 were considered not better than chance alone, whereas models with higher AUC statistics were considered better than chance. We then compared AUC in different models by the Wilcoxon-Mann-Whitney *U* test, which was performed using MedCalc for Windows version 9.2.1.0 (MedCalc Software, Mariakerke, Belgium).

Chapter 4 Results

Part I. Dose-Response Relationship between Lumbar Disc Degeneration and Life Time Cumulative Lifting Load

Of the 754 eligible people, 152 were excluded from this study for the following reasons: 84 people had cancer, 16 people had psychiatric conditions, 13 people had spinal tumors, 4 people had inflammatory spondylopathy, 18 people had compression fractures, and 27 people experienced major back trauma (Fig. 1). A total of 393 fruit market workers (mean age 51.2 years, standard deviation [SD]: 10.0) and 160 walk-in clinic patients (mean age 49.3 years, SD: 11.6) with URIs were included in the analysis in the study; 252 participants were men and 301 participants were women. The demographic characteristics of the participants are shown in Table 1. The BMI was calculated as weight in kilograms divided by length in meters squared (kg/m^2). The fruit market workers (25.3 ± 3.5 kg/m^2) exhibited higher BMI values than the walk-in clinic patients (23.6 ± 3.4 kg/m^2) did, and most participants had more than 15 years of work experience (75.6%). The cumulative lifting load were categorized into tertiles (i.e., $<4.0 \times 10^5$, 4.0×10^5-8.9×10^6, and $\geq 8.9 \times 10^6$ Nh). There were 185, 184, and 184 participants in the low, intermediate, and high lifting load groups, respectively. The fruit market workers were exposed to higher lifting load than the walk-in clinic patients. LBP during the past 6 months was reported by approximately 83.6% of the participants. The prevalence rate of LBP among the fruit market workers (86.3%) was higher than that among the walk-in clinic patients (76.7%).

The intrarater and interrater reliabilities of a modified calculation of the compression load, excluding transporting and unloading time, were 0.998 and 0.992 (ICC), respectively. The reproducibilities of lifting measurements were high for lifting weights (ICC = 0.945), frequency of lifting per day (ICC = 0.914), and working tenure (ICC = 0.943), and moderate for lifting time (ICC = 0.743). The percentage agreement of intrareader reliabilities for the MRI variables ranged from 0.833 to 1.000, as shown in Supplementary Table 1.

The prevalence rates of LDD are shown in Table 2. The most prevalent conditions were dehydration and the bulging of discs. Dehydration was most common at level L4–L5 (69.1 %), followed by L5–S1 (63.7%), L3–L4 (54.4%), L2–L3 (38.5%), and L1–L2 (20.2%). Disc bulging was most common at level L4–L5 (61.8%), followed by L3–L4 (46.1%), L5–S1 (45.4%), L2–L3 (26.4%), and L1–L2 (7.8%). Among the conditions, the most prevalent site of disc height narrowing, spondylolytic spondylolisthesis, and nerve root compression was the L5–S1 level.

The other disc conditions, including disc dehydration, annulus tears, disc bulging, protrusion, extrusion, degenerative spondylolisthesis, and foramina narrowing, were most frequently observed at the L4–L5 level. No disc sequestration was observed in this study. The prevalences of protrusion among Fruit Market population were L1–L2 (3.1%), L2–L3 (2.8%), L3–L4 (4.8%), L4–L5 (19.6 %), and L5–S1 (19.6 %). Among the general population, the prevalences of protrusion were L1–L2 (1.3%), L2–L3 (1.9%), L3–L4 (0.0%), L4–L5 (13.8 %), and L5–S1 (9.4 %).

Table 3 depicts the relationship between the lifetime cumulative lifting load and LDD among the upper lumbar levels, including L1–L2, L2–L3, and L3–L4. Regarding disc dehydration, the participants in the high lifting load group had increased odds ratios (AOR = 1.9, 95% confidence interval [CI] 1.2–3.2; AOR = 2.1, 95% CI 1.2–3.5) at the L2–L3 and L3–L4 levels compared with those in the low lifting load group. After a Bonferroni correction was implemented, the association between lifting load and dehydration remained statistically significant at the L3–L4 level. In addition, the trend analysis was significant (P <.0083). For disc bulging, the association was statistically significant at the L2–L3 and L3–L4 levels (AOR = 2.2, 95% CI 1.3–3.8; AOR = 2.0, 95% CI 1.3–3.4), and the trend analysis was significant ($P < .0083$). Annulus tear, disc height narrowing, protrusion, extrusion, sequestration, degenerative and spondylolytic spondylolisthesis, foramina narrowing, and nerve root compression were not included in the statistical analysis because of a low prevalence among the MRI findings (<3.5%), which limited the analytical power for detecting statistical differences.

Table 4 shows the data regarding the association between lifetime cumulative lifting load and LDD among the lower lumbar levels, including L4–L5 and L5–S1. After Bonferroni correction, the high lifting load group was associated with disc dehydration at the L4–L5 and L5–S1 levels (AOR = 3.1, 95% CI 1.8–5.5; AOR = 2.5, 95% CI 1.5– 4.1), and the trend analysis was significant ($P < .0042$). After Bonferroni correction, the association between disc height narrowing at the L5–S1 level and both the intermediate and high lifting load groups were significant compared with the low lifting load group (AOR = 3.7, 95% CI 1.7–9.0; AOR = 4.1, 95% CI 1.9–10.1), and the trend analysis was significant ($P < .0042$). Regarding disc bulging, the associations with the intermediate lifting load group were significant at both the L4–L5 and L5–S1 levels compared with the low lifting load group (AOR = 2.0, 95% CI 1.3–3.2; AOR = 2.1, 95% CI 1.3–3.3). After a

Bonferroni correction was performed, no association between the lifting load and annulus tears, protrusion, or foramina narrowing was observed. Disc extrusion, sequestration, degenerative and spondylolytic spondylolisthesis, and nerve root compression were not analyzed because of their low prevalence among the MRI findings (<3.5%). In summary, the optimal dose-response relationships between the cumulative lifting load and LDD were observed at the L5–S1 level.

Part II. Threshold Values of Lumbar Load in Lifting for Calculating Lifetime Cumulative Load to Predict Disc Protrusion

A total of 553 volunteers were included in the final analysis; 252 participants were men (mean age 49.8 years, SD: 11.7) and 301 participants were women (mean age 51.3 years, SD: 9.4). The demographic characteristics of the participants are shown in Table 1. The BMI was calculated as weight in kilograms divided by length in meters squared (kg/ m^2). The men (25.6 ± 3.1 kg/ m^2) exhibited higher BMI values than women (24.1 ± 3.8 kg/ m^2) did, 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-S1disc protrusion was good with 0.850**.**

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

Table 3 and 4 showed adjusted odds ratios (aORs) for disc protrusion when lifetime cumulative lifting load was calculated by various thresholds as predictors. In male participants, the cumulative lifting 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 disc protrusion (aOR = 3.1, 95% 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 4). In female participants, the cumulative lifting 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 lifting load above 0 Nh. The cumulative load of above 2800N provided most significant association with L4-S1 disc 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 5).

Part III. Prediction of Lumbar Disc Bulging or Protrusion Based on Anthropometric Factors and Disc Morphology

Of the 553 participants with MRI scans from the previous study, 101 had spondylolisthesis and/or lumbar spine operation at any lumbar level, and were excluded from the analysis, leaving 452 MRI scans in this study. Among them, 210 (46.5%) were men and 242 (53.5%) were women. The mean age was 49.3 years (standard deviation [SD]: 10.5). Their demographic characteristics were shown in Table 1. The mean and SD of body height, body weight, and body mass index (BMI) were 162.8 ± 7.9 (cm), 65.5 ± 11.6 (kg), and 24.6 ± 3.6 (kg/m^2), respectively. BMI was calculated as weight in kilograms divided by length in meters squared (kg/m^2). The disc morphology factors were shown in Table 2. The prevalence rate of disc bulging/protrusion at L3-L4, L4-L5, and L5-S1 was 44.0%, 60.4%, and 43.6%, respectively. None of the participants were found to have extrusion or sequestration. The mean DH of L3-L4, L4-L5, and L5-S1 level was 8.2 ± 1.3 (mm), 9.3 ± 1.4 (mm), and 8.9 ± 1.8 (mm), respectively. The mean DD of L3-L4, L4-L5, and L5-S1 were 31.3 ± 2.7 (mm), 30.8 ± 2.7 (mm), and 29.0 ± 2.6 (mm), respectively. The intra-rater reliability of MRI assessment for disc bulging/protrusion was 0.883, 0.833, and 0.883 at L3-L4, L4-L5, and L5-S1 level (Table 3). For inter-rater and intra-rater reliability of disc morphology measurement, the ICC of DH were 0.878 and 0.917 at L3-L4 level, 0.899 and 0.916 at L4-L5 level, 0.943 and 0.948 at L5-S1 level, respectively. The ICC of DD for inter- rater and intra-rater reliability at L3-L4 level were 0.805 and 0.926, at L4-L5 level were 0.939 and 0.963, and at L5-S1 level were 0.858 and 0.991, respectively (Table 3). The high reliabilities of morphology measurement were found in this study.

Table 4 showed the association between anthropometric factors, disc morphology and disc bulging/protrusion at L3-L4, L4-L5, and L5-S1 level. Model 1 was set up with anthropometric variables including age, gender, body height and body weight to investigate the capacity for predicting disc bulging/protrusion. Model 2 was set up with anthropometric variables, and disc morphology variables including DH and DD for predicting disc bulging/protrusion. Among the anthropometric variables, greater age and higher body weight were significantly associated with disc bulging/protrusion. Body height was negatively associated with disc bulging/protrusion at L3-L4 and L4-L5 levels, but not at L5-S1. Gender was not associated with disc bulging/protrusion. Regarding to disc morphology variables, reduced DH and increased DD were both significantly associated with disc bulging/protrusion.

The ability of model 1 and model 2 to discriminate between participants with and without disc bulging/protrusion at L3-L4, L4-L5 and L5-S1disc level were shown in Figure 1, Figure 2 and Figure 3, respectively. Compared with an AUC = 0.5, AUC statistics at L3-L4 disc level were significantly different from 0.5 in both model 1 (AUC = 0.77 [95% CI = 0.73 – 0.81], P = 0.0001) and model 2 (AUC = 0.81 [95% CI = 0.77 – 0.85], P = 0.0001). The AUC statistics was significantly better for model 2 as compared with model 1 (P < 0.05) (Fig 2). Regarding bulging/protrusion at L4-L5 disc level (Fig 3), AUC statistics were significantly different from 0.5 in both model 1 (AUC = 0.74 [95% CI = 0.70 – 0.78], P = 0.0001) and model 2 (AUC = 0.77 [95% CI = 0.73 – 0.81], P = 0.0001). The AUC statistic was significantly better for model 2 as compared with model 1 (P < 0.05). Regarding bulging/protrusion at L5-S1 disc level (Fig 4), AUC statistics were significantly different from 0.5 in both model 1 (AUC = 0.65 [95% CI = 0.61 – 0.70], P = 0.0001) and model 2 (AUC = 0.67 [95% CI = 0.63 – 0.72], P = 0.0001). The AUC statistic for disc bulging/protrusion at L5-S1 disc level was not significantly different from model 1 and model 2 (P > 0.05). In summary, the AUC statistics were significantly better for model 2 as compared with model 1 at L3-L4 and L4-L5 disc level, indicating better capability of determination for disc bulging/protrusion by adding disc morphology factors to anthropometric factors (model 2).

Chapter 5 Discussion

A. Dose-Response Relationship between Lifetime Cumulative Lifting Load and LDD

This was a cross-sectional study conducted to examine whether the lifetime cumulative lifting load causes dose-dependent LDD. Based on our research, only a few studies have described a dose-response relationship between physical loading and LDD [1-3, 7]. Kelsey indicated that people lifting objects heavier than 11.3 kg (25 lbs.) over 25 times per day exhibited more than 3 times the risk for developing acute prolapsed lumbar intervertebral discs than did people who do not [7]. Seilder et al showed that a positive dose-response relationship exists between lumbar disc herniation and the cumulative lumbar load through manual material handling [1-3]. The OR was 1.7 for men in the middle exposure group (5–21.51 × 10^6 Nh), whereas the OR was 2.4 for women in the second-highest exposure group (4.04–14.47 × 10^6 Nh) [3]. In our study, the workers exposed to intermediate lifting loads (4.0 × 10^5–8.9 × 10^6 Nh) were 2.1 times more likely to present with disc bulging at L5–S1 compared with those exposed to low lifting load (<4 × 10^5 Nh). We determined that workers exposed to intermediate lifting load exhibited a 3.7-fold of experiencing disc height narrowing at L5–S1, which is consistent with the findings of Seilder [3]. In our study, observable health effects exerted on the intervertebral discs were observed among the lower lumbar levels.

B. Estimation of the Disc Compression Load

Direct measurement of lumbar spine load when conducting in vivo studies requires implanting a transducer or sensor into the disc. This type of study is rarely attempted because of the ethical considerations regarding such an invasive procedure. Numerous methods have been developed for estimating the disc compression load. Among these methods, computerized biomechanical modeling is considered the most precise method for estimating the disc compression load. The 3DSSPP was established based on several biomechanical studies [20, 55, 59, 82-85], and anthropometric data from a U.S. industrial database were applied in estimating the lumbar disc compression load [49]; this method has been used in field investigations [51, 73, 74, 86]. The advantage of this computerized biomechanical model is its capability for estimating the disc compression load within a single exertion. This model was validated by comparing it with 4 optimization models, and high correlation rates were obtained (r > 0.8) [82]. Moreover, the model has been used as the standard model for estimating the disc compression load [73]. The limitation of 3DSSPP is that it cannot be used for simulating dynamic exertions. Therefore, in this study, the work tasks were divided into sequences of static postures, and each posture was analyzed.

In this study, pushing and pulling tasks were not included in load determination. We observed that fruit market workers did not typically practice pushing and pulling, potentially causing the lifetime cumulative load to be underestimated among the other participants who performed pushing or pulling tasks in their jobs. These factors were not considered to have generated bias in our findings because pushing and pulling involve exerting much smaller compression load on lumbar discs than lifting does. Similarly, if the participants belonging to the low lifting load group actually exposed to higher lifting load than recorded, this potentially caused random errors and several values regarding the relationship between lifting exposure and LDD to be underestimated. Exposure to lifting during leisure and home activities were not considered, potentially causing misclassification and error in the cumulative lifting load estimates.

C. The Effect of Lifting Load Vary in Different LDD and Lumbar Levels

Compared with previous studies that focused on only 1 or 2 disc degenerations

[1, 2, 7] at specific lumbar levels, this study evaluated various LDD and examined each lumbar level. The results indicated that varying lifting loads seem to exert different effects to various LDD, as well as to different lumbar levels. For example, disc bulging caused by carrying intermediate load was observed at the L2–L3 and L3–L4 levels, and bulging caused by carrying high lifting load was detected at the L4–L5 and L5–S1 levels. However, dehydration was observed only in the group that carried high lifting load. Disc height narrowing was detected in both groups that carried intermediate and high lifting load, but only at the L5–S1 level. Regarding the most prevalent sites, the study results indicated that disc height narrowing, spondylolytic spondylolisthesis, and nerve root compression were mostly detected at the L5–S1 level, and that the other LDD were common at the L4–L5 level. These results are consistent with those of previous studies [5, 6, 20, 30]. Generally, most studies on LDD have observed that the effects occur more frequently and severely at lower level than at upper level [5, 6, 20, 30]. Systemic factors such as age, smoking habits, and genetics are expected to have similar effects at all lumbar levels. The observation that severe degeneration frequently occurred at the L4–L5 and L5–S1 levels supported the hypothesis that mechanical loading may play a crucial role in disc pathogenesis [20]. Although many of the

ORs were statistically significant, they were minor (<3.0), suggesting that the associations between the lifting load and degenerative-disc-related MRI findings were not strong. Based on the literature, several critical risk factors, such as hereditary factors and age, may lead to the development of degenerative discs [9, 29, 31]. Nevertheless, the significant ORs identified in this study suggested that lifting exposure contributes to the development of degenerative discs and should not be ignored.

D. Study Population Selection

The walk-in clinic patients with URI were recruited to incorporate a background population who was minimally exposed to lifting load. The ideal study participants would have been from one industry that involved a broad spectrum of lifting exposure. However, most fruit market workers were exposed to heavy lifting, except for a small percentage of administrative workers. Thus, recruiting a group of participants with low lifting exposure as a comparison group enhanced this study. Because these walk-in patients were employed in various occupations, they were predominantly grouped into the low lifting exposure tertile. In addition, URI are among the most common conditions in the general population. Therefore, these walk-in patients with URI were regarded as representative of the general population.

Moreover, the differences among the study populations may have confounded the association between cumulative lifting load and LDD. The gender and age distributions of the participants from the 2 populations were similar. The fruit market workers lifted heavier load and exhibited higher BMIs, smoking durations, and lower education level than the clinic patients did. The lifting exposure patterns among the fruit market workers were more consistent compared with those of the walk-in clinic patients. When we grouped the participants into tertiles, the possibility of misclassification was considered acceptable. In addition, from a statistical point of view, such misclassification is unlikely to cause an overestimation of the ORs, and an underestimation of the actual results is more likely to occur. The BMI was associated with our findings regarding disc dehydration and bulging. Age is strongly associated with LDD [5, 29] , and degenerative changes in the lumbar spine are observed approximately 10 years earlier in men than in women [31] . Smoking has been associated with LDD [35] ; however, findings regarding smoking have not been consistent. Education level has probably no effect to LDD. People with lower education level are more likely to choose physically demanding work than people with higher education levels, thereby exposing themselves to high levels of lifting. Therefore, we adjusted age, gender, BMI, and smoking habits to minimize the possible confounding that might occur. After the adjustment, the ORs were decreased compared with the crude ORs, suggesting that these adjusted factors influence the outcome; therefore, the effects of lifting can be detected.

E. The Current Recommended Lifting Limits Would be Inappropriate Limits for Calculating the Lifetime Cumulative Liftload

This study attempted to determine the optimal threshold values of load per lift which allow for best prediction of disc protrusion by cumulating exposures. The recommended lifting limits currently in use do not appear to be optimal for several reasons. The NIOSH 3400 N, is widely used as weight limit in the workplace by ergonomists as well as health and safety practitioners [64, 65]. It is based on the studies by Evans and Lisner, and Sonoda [67, 87]. 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. Beside, statistics provided by the Workplace Safety and Insurance Board regarding the reporting of low back pain indicate no decrease in the percentage of low back injuries, despite the many recommended workplace limits [64]. Thus, focusing only on reducing the cut points may be insufficient for mitigating the risk. In most circumstances, two pathways for injury are considered: injury may result from spontaneous tissue failure caused by peak load or accumulation of microdamage from repetitive submaximal loads [57, 83]. For example, sheep shearers were reported six-fold the mean number of injuries (20% of these involve injuries to the back) compared with workers in other occupations in Australia [56]. Regardless, Marshall and Burnett reported the average peak load among sheep shearers ranged from 2200 to 3000 N [88], which is lower than the NIOSH action limit of 3400 N at the L4–L5 intervertebral disc [64]. The peak load might not be responsible for LBP in this occupation; rather, it might be caused by cumulative load over the entire workday and, consequently, over the course of the career lifetime. In this case, following the NIOSH 3400 N standard may not prevent low back injury. The cumulative load from lighter and more repetitive tasks might be a critical risk factor of injury, thus necessitating a thorough evaluation. Those recommended weight limits would be inappropriate lifting limits for calculating the lifetime cumulative liftload because they were proposed as limited peak loads for preventing spontaneous tissue failure [55, 59, 60, 64].

F. Utilizing the Concept of Threshold per Lift Load in Calculating Lifetime Cumulative Load

To our best knowledge, only few studies examined dose-effect relationship between lifetime cumulative lifting load and disc protrusion. Seilder *et al* conducted a thorough investigation of all past lifting load for the participants [2]. They showed that male workers who had been exposed to 5 - 21.5 × 10^6 Nh lifetime lifting load exhibited a 1.7-fold risk of disc protrusion comparing to those exposed to 0 – <5 × 10^6 Nh, suggesting cumulative effects of all lifting loads, without threshold, on disc protrusion [1-3]. In a later study [89], participants who had been exposed to high lifting load (≥8.9 × 10^6 Nh) exhibited an odds ratio of 2.2 (95% confidence interval 1.2–4.1) for disc protrusion, as compared to those exposed to a low lifting load (<4.9 × 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 disc protrusion.

G. Threshold per Lift Load between Genders

Considering disc 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 discs than women [42]. The larger areas allowed men to endure higher compression forces. Thus, the results of this investigation suggest that different threshold values of lifting load should be applied to men and women in the workplace.

H. The Application of Lifetime Cumulative Lifting Load Calculation in the Workplace

By using 3D SSPP estimation, 3000 N compression force was generated on L4-5 lumbar disc when a man (175 cm body height and 70 kg body weight) lifts up a 35 kg object in a standing posture, or 20 kg in a stoop posture. Our results showed that male participants exposed to cumulative load of $\geq 5.6\times10^{6}$ Nh had 3.1-fold risk of disc protrusion comparing to those exposed to $<2.5\times10^{5}$ Nh when 3000 N threshold was applied. For example, if a man’s working cycle involves lifting up from ground a 50 kg object (duration 2 sec), walking for 10 second, and putting down the object (2 sec), he is exposed to 16.8 Nh. If he performs this cycle for 133 times a day for 10 years, he will be exposed to 5.6×10^{6} Nh. Such exposure or greater will be associated with 3.1 fold higher risk of disc protrusion compared to those with low lifting exposure. Regarding to women, 2800 N compression force was generated when she (160cm body height and 55kg body weight) lifts up a 30 kg object in a standing posture, or 19 kg in a stoop posture. Our results showed that female participants exposed to cumulative load of $\geq 1.8\times10^{6}$ Nh had 2.7-fold risk of disc protrusion comparing to those without lifting when 2800N threshold was applied. If a woman’s working cycle involves lifting up from ground a 35 kg object (2 sec), walking for 10 second, and putting down the object (2 sec), she is exposed to 13.0 Nh. If she performs this cycle for 55 times a day for 10 years, she will be exposed to 1.8×10^{6} Nh. Such exposure or greater will be associated with 2.7 fold higher risk of having disc protrusion compared to those without lifting.

I. The Association between Disc Height, Disc Depth and Disc Bulging/Protrusion

In the present study, our finding showed that reduction of DH was associated with disc bulging/protrusion at L3-L4, L4-L5 and L5-S1 level, which was consistent with other studies. Brinckmann and Grootenboer found a disc height reduction and an increase in disc bulge occur in proportion to the amount of disc tissue removed [39]. In another study, the author s found fracture and discectomy result in an increase of the radial disc bulge and a decrease of the disc height [40]. These studies revealed that there was a relation between DH and disc bulge. However, Tibrewal showed that patients with disc herniation had reduced DH compared with the normal, but the differences did not reach statistical significance [37]. The reason might be because of the smaller samples size in this study and the greater anatomic variation at the L5-S1 disc level. It has long been clinical experience that patients with disc bulging /protrusion have disc space narrowing [37], and our study has quantified this experience. In addition to DH, we observed DD was closely related to disc bulging/protrusion at L3-L4, L4-L5 and L5-S1 level. It seems appear that not only DH was associated with disc bulging/protrusion, but also DD. According to Natarajan’s study, it suggested that changes in disc volume or disc area might be more rational to disc bulging than decrease of DH [41].

Therefore, we might take both DH and DD into account when considering disc bulging /protrusion. In further, the predicting model with anthropometric and morphology factors had better capacity to predict disc bulging/protrusion compared with model with only anthropometric factors. The findings suggested that disc morphology factors, disc height and disc depth, is valuable to predict disc bulging/protrusion.

J. The Association between Anthropometric Factors and Disc Bulging/Protrusion

Regarding to anthropometric factors, the result showed greater age was associated with disc bulging/protrusion. A number of studies have indicated aging is an important risk factor to disc bulging/protrusion. Videman had indicated LDD including disc dehydration, bulge and disc height narrowing show an increasing prevalence with increasing age [18]. Another study reported that increasing age correlated with a higher prevalence of disc bulge [20]. Twomey showed the intervertebral disc become more convex in the old age [32]. In addition, greater body weight was associated with disc bulging/protrusion, which was consistence with the Hrubec’s results. He reported body height and body weight were positively associated with the risk of disc herniation diagnosed in United States

Army hospital [15]. The surrounding literatures on age and body weight to bulging/protrusion appears to generally compatible with the results obtained in this study. However, body height was negative associated with disc bulging/protrusion at L3-L4 and L4-L5 levels in this study. Some studies have indicated that tallness is a factor associated with an increased risk of herniation [15, 17], but Kelsey's studies failed to support such relationship [33, 34], as well as our study. In a study on disc herniation, men with a height of 180 cm or more showed a relative risk of 2.3 and women with a height of 170 cm or more 3.7, compared with those who were more than 10 cm shorter. The author reported that body height may be an important contributors to the herniation of lumbar intervertebral disc [17]. The reason that our result did not observed this relation might be explained the average body height (162.8 ± 7.9 cm) of our participants was not as high as the previous study.

One thing should be considered is the diurnal variation of the intervertebral disc in the disc height measurement. The diurnal variation in disc height was reported similar in the lower three lumbar discs [90]. The MRI assessments in this study were taken between 3 and 6 hours after rising, the diurnal loss was considered to be similar among the participants. Therefore, we assumed that the diurnal change is unlikely to have influence on measurement of disc height.

K. The Ability of Disc Morphology factor to Predict Disc Bulging/Protrusion at L5-S1level

At L5-S1 disc level, the ability to predict disc bulging/protrusion of model 2 is not significantly better than model 1.The result suggested that disc morphology might not have sufficient effect to bulging/protrusion at L5-S1level. The reason could be due to the wide individual variation of L5-S1 disc. The lumbar disc height generally increased toward the lower lumbar level except for L5-S1. Accordingly, narrowing of disc height is usually determined clinically on plain radiographs in comparison with the adjacent disc heights, particular one level above. However, narrowing of L5-S1 disc height was difficult to be judged on plain radiographs [36]. For these reasons, disc morphology might not be useful to predict disc bulging/protrusion at L5-S1level.

L. Limitations

This study had several limitations. Because this study was a cross-sectional study, it was subject to the healthy worker survivor effect. The participants had to be mobile enough to visit the NTUH to take MRI assessment. In other words, participants with the more severe symptoms with pain were might not be included. For example, disc bulging at the L4–L5 and L5–S1 levels was observed more frequently among the participants who lifted intermediate load than among those who lifted high lifting load. Moreover, disc sequestration was not observed in this study. In addition, the prevalence of disc extrusion and spondylolytic spondylolisthesis was lower compared with that reported in previous studies [30, 91]. This might be because severely affected workers have left their jobs. Consequently, based on the MRI results, several degenerative-disc-related conditions were not analyzed because of low prevalence.

The reliance on the participants' memories regarding their occupational history and relevant work tasks from several decades ago is the other limitation. Although the repeatability of self-reported and specific current job tasks was examined and determined to be satisfactory, the reliability of the information pertaining to previous jobs was difficult to determine. To enhance reliability, a structured interview was administered to provide the participants with adequate time for examining the work details of their previous jobs. The trained interviewers used common milestones in life to help the participants recall the necessary details. The trained interviewers captured the working simulation photos by following a standard procedure. Several studies have indicated that, compared with direct measurements, the validity of self-reported data is lacking [50, 92, 93]. By contrast, Pope et al [94] demonstrated the accuracy of self-reported manual material handling activities and presented satisfactorily accurate results regarding frequency, duration, and amplitude. Direct measurements obtained using work or laboratory simulations yield the most accurate information; however, using such methods in retrospective studies involving relatively large sample sizes is impractical.

Another limitation is 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. One of the limitations is the effect of aging on DH and DD may cause overestimation to the predicting model. Several studies had reported that DH or DD was related to age [18, 32, 41-44]. Natarajan found there is a decline of DH after the fifth decade of life [41]. Amonookuofi showed that disc height and diameter vary significantly in the different age groups [42]. The sizes of disc increase as a person age [42]. In another study, the maximum DH was greater in the older (50-60 years) than in the younger individuals (20-30 years) [44]. It was presumed to be a result of the microfracture of the endplate during adult life, which leads to a more concave form of the intervertebral disc [44]. However, Koeller had different observation that the average DH is almost independent of age [45]. Therefore, we then assessed the correlation of age, DH and DD. The correlation between age and DH were $r = -0.025$, $p > 0.05$ at L3-L4, $r = -0.063$, $p > 0.05$ at L4-L5, and $r = 0.116$, $p = 0.01$ at L5-S1. The correlation between age and DD were $r = 0.151$, $p = 0.001$ at L3-L4, $r = 0.180$, $p = 0.0001$ at L4-L5, and $r = 0.121$, $p = 0.009$ at L5-S1. The result showed that the correlation between age and disc morphology was low in our study. In further, we adjusted age to minimize the possible confounding that might occur. After adjustment, we assumed that possible overestimation of predictive model might not be serious.

Chapter 6 Conclusion

In conclusion, the results suggest a dose-response relationship between the cumulative lifting load and LDD. Based on the MRI observations, the effects include disc dehydration, disc height narrowing, and disc bulging, especially at the lower lumbar levels. The lifting load apparently exerts different effects to various LDD, as well as to different disc levels. In further, we applied the concept of threshold value per lift into lifetime cumulative lifting load calculation. Cumulative lifting load predicted L4-S1 disc protrusion best when the threshold value was set at 3000 N for men, and 2800 N for women. Our data also provides evidence for association between disc morphology and disc bulging/protrusion at L3-L4, L4-L5 and L5-S1 level. A predicting model using anthropometric factors and disc morphology to predict disc bulging/protrusion at L3-L4, L4-L5 level was developed. This predicting model could be used on plain film to helping clinical diagnosis and increased resource utilization.

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Publication List

A. Referred papers

Hung YJ, Shih TT, Chen BB, Hwang YH, Ma LP, Huang WC, Liou SH, Ho IK, Guo YL. The Dose-Response Relationship Between Cumulative Lifting Load and Lumbar Disk Degeneration Based on Magnetic Resonance Imaging Findings. Phys Ther. 2014 Nov;94(11):1582-93.

Hung YJ, Shih TT, Chen BB, Hwang YH, Ho IK,Ma LP, Liou SH, Guo YL. Prediction of Lumbar Disc Bulging or Protrusion Based on Anthropometric Factors and Disc Morphology. Clinical Orthopaedics and Related Research. (Under review)

Hung YJ, Shih TT, Chen BB, Hwang YH, Liou SH, Guo YL, Ho IK. Threshold Values of Lumbar Load in Lifting for Calculating Lifetime Cumulative Load to Predict Disc Protrusion. Occup Environ Med. (Submit)

Chin W, Guo YL, Hung YJ, Yang CY, Shiao JS. Short sleep duration is dose-dependently related to job strain and burnout in nurses: A cross sectional survey. Int J Nurs Stud. 2014 Oct [Epub ahead of print]

B. Conference papers

Risk Factors and Prevalence of Musculoskeletal Disorder among Nursing Personnel in Taiwan: Results of a Questionnaire Survey. Premus 2007 Sixth International Scientific Conference on Prevention of Work-Related Musculoskeletal Disorder, Boston, USA, Aug 27-31, 2007(Poster Presentation)

Dose-response relationship with occupational herniated intervertebral disc (HIVD) in Taiwan. Conference of 41th Asia-Pacific Academic Consortium for Public Health (APACPH), Dec 4-6, 2009, Taipei, Taiwan. (Poster Presentation)

Occupational herniated intervertebral disc (HIVD) in Taiwan-physical, occupational and genetic interaction. Conference of 41th Asia-Pacific Academic Consortium for Public Health (APACPH), Dec 4-6, 2009, Taipei, Taiwan. (Poster Presentation)

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Association of COL11A1 with lumbar disc degeneration (LDD) in Taiwan young adults：The 21st Asian Conference on Occupational Health, Fukuoka, Japan.Sep 2-4. (Poster Presentation)

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Part I. Dose-Response Relationship between Lumbar Disc Degeneration and Life Time Cumulative Lifting Load

Table 1.Demographic characteristics of the study participants

Variables	Fruit Market Worker, N=393	Walk-in patients, N=160	All, N=553
	N (%)	N (%)	N (%)
Age, mean ± SD (years)	51.2 ± 10.0	49.3 ± 11.6	50.6 ± 10.5
< 40	54 (13.7)	38 (23.8)	92 (16.6)
40–50	89 (22.7)	33 (20.6)	122 (22.1)
50–60	179 (45.6)	58 (36.3)	237 (42.9)
≥ 60	71 (18.1)	31 (19.4)	102 (18.4)
Gender			
Male	183 (46.6)	69 (43.1)	252 (45.6)
BMI, mean ± SD (kg/m^2)	25.3 ± 3.5	23.6 ± 3.4	24.8 ± 3.5
< 24	133 (33.8)	91 (56.9)	224 (40.5)
24–27	156 (39.7)	40 (25.0)	196 (35.4)
≥ 27	104 (26.5)	29 (18.1)	133 (24.1)
Lifetime work tenure (years)			
< 15	85 (21.7)	50 (31.3)	135 (24.5)

15–30	132 (33.7)	77 (48.1)	209 (37.9)
≥ 30	175 (44.6)	33 (20.6)	208 (37.7)
Education Level			
Junior high and below	164 (42.4)	31 (19.6)	195 (35.8)
Senior high school	197 (50.9)	57 (36.1)	254 (46.6)
College or above	26 (6.7)	70 (44.3)	96 (17.6)
Lifetime cumulative lifting load (Newton × hours, Nh) by tertiles			
Low lifting exposure ($<4.0 \times 10^5$)	55 (14.0)	123 (76.9)	185 (33.4)
Intermediate lifting exposure (4.0×10^5 – 8.9×10^6)	159 (40.5)	28 (17.5)	184 (33.3)
High lifting exposure ($\geq 8.9 \times 10^6$)	179 (45.6)	9 (5.6)	184 (33.3)
Low back pain (within 6 months)	335 (86.3)	122 (76.7)	457 (83.6)
Cigarette smoking (pack-years)			
0	294 (75.8)	132 (82.5)	426 (77.7)
1–20	37 (9.5)	15 (9.4)	52 (9.5)
≥ 20	57 (14.7)	13 (8.1)	70 (12.8)

BMI, body mass index; SD, standard deviation

Table 2. Prevalence of disc-related degenerative findings on MRI images of the lumbar spine in the study

Degeneration sign	Intervertebral disc level				
	L1–L2	L2–L3	L3–L4	L4–L5	L5–S1
	N (%)	N (%)	N (%)	N (%)	N (%)
Dehydration	112 (20.2)	213 (38.5)	301 (54.4)	382 (69.1)	352 (63.7)
Annulus tear	1 (0.2)	10 (1.8)	30 (5.4)	113 (20.4)	91 (17.9)
Disc height narrowing	16 (2.9)	23 (4.2)	26 (4.7)	31 (5.6)	74 (13.4)
Bulging	43 (7.8)	146 (26.4)	255 (46.1)	342 (61.8)	251 (45.4)
Protrusion	14 (2.5)	14 (2.5)	19 (3.4)	99 (17.9)	92 (16.6)
Extrusion	0 (0.0)	0 (0.0)	0 (0.0)	3 (0.5)	1 (0.2)
Sequestration	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Degenerative spondylolisthesis	0 (0.0)	1 (0.3)	14 (2.5)	61 (11.0)	11 (2.0)
Spondylolytic spondylolisthesis	0 (0.0)	0 (0.0)	0 (0.0)	3 (0.5)	15 (2.7)
Foramina narrowing	0 (0.0)	6 (1.1)	21 (3.8)	74 (13.4)	65 (11.8)
Nerve root compression	0 (0.0)	0 (0.0)	5 (0.9)	16 (2.9)	22 (4.0)

Table 3. The association between disc degeneration and life-time lifting exposure (Newton × hours , Nh) among upper lumbar level$

	Intervertebral disc level								
	L1–L2			L2–L3			L3–L4		
	%	OR	AOR	%	OR	AOR	%	OR	AOR
Dehydration									
<4.0 ×10^5 Nh	14.6	1	1	26.0	1	1	38.9	1	1
4.0 ×10^5– 8.9 ×10^6 Nh	17.4	1.2 (0.7-2.2)	1.0 (0.5-1.8)	36.4	1.6* (1.1-2.6)	1.2 (0.7-2.1)	54.4	1.9*@ (1.2-2.8)	1.3 (0.8-2.2)
≥8.9 ×10^6 Nh	28.8	2.4 *@ (1.4-4.0)	1.3 (0.7-2.4)	53.3	3.3*@ (2.1-5.1)	1.9* (1.2-3.2)	70.1	3.7 *@ (2.4-5.7)	2.1* @ (1.2-3.5)
P-values for trend		*@			*@	*		*@	* @
Bulging									
<4.0 ×10^5 Nh	4.3	1	1	14.1	1	1	31.9	1	1
4.0 ×10^5– 8.9 ×10^6 Nh	10.3	2.5* (1.1-6.3)	2.1 (0.9-5.4)	27.2	2.3*@ (1.4-3.9)	1.7 (1.0-3.0)	43.5	1.6* (1.1-2.5)	1.2 (0.8-2)
≥8.9 ×10^6 Nh	8.7	2.1 (0.9-5.3)	1.1 (0.5-3)	38.0	3.8 *@ (2.3-6.3)	2.2* @ (1.3-3.8)	63.0	3.6 *@ (2.4-5.6)	2.0* @ (1.3-3.4)
P-values for trend					*@	*@		*@	*@

$ Adjusted for age, gender, BMI and smoking (pack-yr)

* Statistically significant, p< .05

@ Statistically significant after Bonferroni correction, p< .0083

OR, odds ratios; AOR, adjusted odds ratios

Table 4. The association between disc degeneration and life-time lifting exposure (Newton × hours, Nh) among lower lumbar level#

	Intervertebral disc level					
	L4–L5			L5–S1		
	%	OR	AOR	%	OR	AOR
Dehydration						
$<4.0 \times 10^5$ Nh	1.4	1	1	47.6	1	1
$4.0 \times 10^5 – 8.9 \times 10^6$ Nh	72.3	2.5*@ (1.6-3.8)	2.0* (1.2-3.4)	66.9	2.2*@ (1.5-3.4)	1.9* (1.2-3.1)
$\geq 8.9 \times 10^6$ Nh	83.7	4.9 *@ (3.0-8.0)	3.1*@ (1.8-5.5)	76.6	3.6*@ (2.3-5.7)	2.5* @ (1.5-4.1)
P-values for trend		*@	*@		*@	*@
Annulus tear						
$<4.0 \times 10^5$ Nh	20.0	1	1	12.4	1	1
$4.0 \times 10^5 – 8.9 \times 10^6$ Nh	19.6	1 (0.6-1.6)	0.9 (0.6-1.6)	20.1	1.8 * (1-3.2)	2.0* (1.1-3.7)
$\geq 8.9 \times 10^6$ Nh	21.7	1.1 (0.7-1.8)	1.0 (0.6-1.8)	21.2	1.9 * (1.1-3.4)	2.2* (1.2-4.2)
P-values for trend					*	*
Disc height narrowing						
$<4.0 \times 10^5$ Nh	3.2	1	1	4.3	1	1
$4.0 \times 10^5 – 8.9 \times 10^6$ Nh	5.4	1.7	1.4	15.2	4.0*@	3.7*@

			(0.6-5.1)	(0.5-4.4)		(1.8-9.6)	(1.7-9.0)
$\geq 8.9 \times 10^6$	Nh	8.2	2.6*	1.4	20.7	5.8*@	4.1 *@
			(1-7.6)	(0.5-4.3)		(2.7-13.6)	(1.9-10.1)
P-values for trend			*			*@	*@
Bulging							
$<4.0 \times 10^5$	Nh	45.4	1	1	30.8	1	1
$4.0 \times 10^5 - 8.9 \times 10^6$	Nh	67.9	2.5*@	2.0*@	51.6	2.4*@	2.1*@
			(1.7-3.9)	(1.3-3.2)		(1.6-3.7)	(1.3-3.3)
$\geq 8.9 \times 10^6$	Nh	72.3	3.1*@	1.7*	53.8	2.6 *@	1.9*
			(2-4.9)	(1.1-2.8)		(1.7-4)	(1.2-3.1)
P-values for trend			*@	*		*@	*
Protrusion							
$<4.0 \times 10^5$	Nh	12.4	1	1	11.4	1	1
$4.0 \times 10^5 - 8.9 \times 10^6$	Nh	22.3	2.0*	1.8*	17.4	1.6	1.7
			(1.2-3.6)	(1-3.3)		(0.9-3)	(0.9-3.1)
$\geq 8.9 \times 10^6$	Nh	19.0	1.7	1.3	21.2	2.1*	2.2*
			(0.9-3)	(0.7-2.4)		(1.2-3.8)	(1.2-4.1)
P-values for trend						*	*
Foramina narrowing							
$<4.0 \times 10^5$	Nh	8.1	1	1	4.9	1	1
$4.0 \times 10^5 - 8.9 \times 10^6$	Nh	13.6	1.8	1.6	12.5	2.8 *	2.4*
			(0.9-3.6)	(0.8-3.4)		(1.3-6.5)	(1.1-5.8)
$\geq 8.9 \times 10^6$	Nh	18.5	2.6*	1.7	17.9	4.3* @	2.5*

	(1.4-5.0)	(0.8-3.4)		(2.1-9.8)	(1.2-6.1)
P-values for trend	*@			*@	*

$ Adjusted for age, gender, BMI and smoking (pack-yr)

* Statistically significant, p< .05

@ Statistically significant after Bonferroni correction, p< .0042

OR, odds ratios; AOR, adjusted odds ratios

Supplementary Table 1. Percentage agreement for intra-reader reliability of all MRI variables

Degeneration sign	Intervertebral disc level					
	L1- L2	L2- L3	L3- L4	L4- L5	L5-S1	L1-S1
Dehydration	0.867	0.883	0.883	0.933	0.900	0.893
Annulus tear	1.000	0.950	0.983	0.883	0.883	0.940
Disc height narrowing	0.967	0.967	0.933	0.950	0.917	0.947
Bulging	0.933	0.883	0.883	0.833	0.883	0.833
Protruding	0.983	0.950	0.967	0.933	0.917	0.950
Extruding	1.000	1.000	1.000	1.000	1.000	1.000
Sequestration	1.000	1.000	1.000	1.000	1.000	1.000
Degenerative spondylolisthesis	1.000	1.000	0.967	0.967	0.983	0.983
Spondylolytic spondylolisthesis	1.000	1.000	1.000	1.000	1.000	1.000
Foramina narrowing	1.000	0.975	0.959	0.842	0.925	0.940
Nerve root compression	1.000	1.000	0.975	0.967	0.933	0.975

Supplementary Table 2. Kappa value for intra-reader reliability of all MRI variables

Degeneration sign	Intervertebral disc level					
	L1- L2	L2- L3	L3- L4	L4- L5	L5-S1	L1-S1
Dehydration	0.610	0.759	0.741	0.804	0.721	0.727
Annulus tear	1.000	0.545	0.900	0.685	0.708	0.768
Disc height narrowing	0.483	- 0.017	0.000	0.700	0.621	0.357
Bulging	0.838	0.860	0.828	0.765	0.861	0.830
Protruding	0.900	0.545	0.856	0.867	0.833	0.800
Extruding	1.000	1.000	1.000	1.000	1.000	1.000
Sequestration	1.000	1.000	1.000	1.000	1.000	1.000
Degenerative spondylolisthesis	1.000	1.000	0.483	0.870	0.659	0.802
Spondylolytic spondylolisthesis	1.000	1.000	1.000	1.000	1.000	1.000
Foramina narrowing	1.000	1.000	0.688	0.513	0.740	0.788
Nerve root compression	1.000	1.000	0.573	0.650	0.565	0.758

Part II. Threshold Values of Lumbar Load in Lifting for Calculating Lifetime Cumulative Load to Predict Disc Protrusion

Table 1. Demographic characteristics of the study participants

Variables	Male, N= 252	Female, N= 301	All, N= 553
	N (%)	N (%)	N (%)
Age, mean ± SD (years)	49.8 ± 11.7	51.3 ± 9.4	50.6 ± 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)
≥ 60	51 (20.2)	51 (16.9)	102 (18.4)
BMI, mean ± SD (kg/m^2)	25.6 ± 3.1	24.1 ± 3.8	24.8 ± 3.5
< 24	73 (29.0)	151 (50.2)	224 (40.5)
24~<27	103 (40.8)	93 (30.9)	196 (35.4)
≥ 27	76 (30.2)	57 (18.9)	133 (24.1)
Lifetime work tenure (years)			
< 15	59 (23.4)	76 (25.3)	135 (24.5)
15~<30	82 (32.5)	127 (42.3)	209 (37.9)
≥ 30	111 (44.0)	97 (32.3)	208 (37.7)
Education Level			
Junior high and below	78 (31.5)	117 (39.4)	195 (35.8)
Senior high school	121 (48.8)	133 (44.8)	254 (46.6)
College or above	49 (19.8)	47 (15.8)	96 (17.6)
Low back pain (within 6 months)	211 (84.1)	246 (83.1)	457 (83.6)
Cigarette smoking (pack-years)			
0	138 (55.0)	288 (95.7)	426 (77.7)

1~<20	43 (17.1)	13 (4.3)	52 (9.5)
≥ 20	70 (27.9)	0 (0.1)	70 (12.8)
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. Performance of predictive abilities for L4-S1 disc protrusion as measured by area-under-curve (AUC) of receiver-operator characteristic (ROC) curve, R-square, Akaike information criterion (AIC), and Bayesian information criterion (BIC) of cumulating lifetime lifting load using various threshold values in male participants

Proposed threshold value (Newton)	AUC of ROC	R-Square	AIC	BIC
0	0.654	0.0556	-383.820	-381.297
2000	0.668	0.0631	-385.829	-383.306
2100	0.672	0.0650	-386.332	-383.809
2200	0.667	0.0628	-385.749	-383.227
2300	0.672	0.0647	-386.257	-383.734
2400	0.652	0.0608	-385.196	-382.673
2500	0.652	0.0606	-385.145	-382.623
2600	0.663	0.0678	-387.078	-384.555
2700	0.679	0.0790	-390.142	-387.620
2800	0.680	0.0785	-389.994	-387.471
2900	0.677	0.0743	-388.850	-386.328
3000	0.686	0.0797	-390.331	-387.809
3100	0.680	0.0731	-388.531	-386.009
3200	0.675	0.0673	-386.951	-384.429
3300	0.672	0.0648	-386.269	-383.747
3400	0.674	0.0676	-387.029	-384.506
3500	0.653	0.0606	-385.154	-382.631
3600	0.650	0.0568	-384.134	-381.611
3700	0.649	0.0561	-383.930	-381.407
3800	0.648	0.0562	-383.976	-381.454
3900	0.646	0.0547	-383.577	-381.054
4000	0.639	0.0546	-383.546	-381.023

The association between lifetime lifting load for L4-S1 disc protrusion were analyzed by using logistic regression, adjusting for age, body mass index (BMI), and smoking

Table 3. Performance of predictive abilities for L4-S1 disc protrusion as measured by area-under-curve (AUC) of receiver-operator characteristic (ROC) curve, R-square, Akaike information criterion (AIC), and Bayesian information criterion (BIC) of cumulating lifetime lifting load using various threshold values in female participants

Proposed threshold value (newton)	AUC of ROC	R-Square	AIC	BIC
0	0.595	0.0163	-498.187	-495.855
2000	0.596	0.0162	-498.160	-495.828
2100	0.599	0.0214	-497.756	-495.320
2200	0.602	0.0232	-498.324	-495.889
2300	0.613	0.0283	-499.892	-497.456
2400	0.593	0.0200	-497.319	-494.884
2500	0.602	0.0218	-497.879	-495.443
2600	0.594	0.0187	-496.938	-494.503
2700	0.603	0.0253	-498.948	-496.513
2800	0.615	0.0321	-501.061	-498.625
2900	0.604	0.0248	-498.812	-496.377
3000	0.615	0.0302	-500.478	-498.043
3100	0.614	0.0287	-500.020	-497.584
3200	0.613	0.0307	-500.626	-498.191
3300	0.601	0.0250	-498.876	-496.441
3400	0.594	0.0218	-497.882	-495.447
3500	0.581	0.0143	-495.593	-493.158
3600	0.585	0.0181	-496.748	-494.312
3700	0.582	0.0194	-497.155	-494.719
3800	0.580	0.0158	-496.054	-493.619
3900	0.577	0.0153	-495.894	-493.459
4000	0.575	0.0156	-495.970	-493.534

The association between lifetime lifting load for L4-S1 disc protrusion were analyzed by using logistic regression, adjusting for age, body mass index (BMI), and smoking

Table 4. The association (as shown by adjusted odds ratio, aOR) between L4-S1 disc protrusion and lifetime cumulative lifting load when only lift loads above different threshold values were calculated in male participants

Lifetime cumulative lifting load (Newton-hr)			n	disc protrusion at lower disc 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 5. The association (as shown by adjusted odds ratio, aOR) between L4-S1 disc protrusion and lifetime cumulative lifting load when only lift loads above different threshold values were calculated in female participants

Lifetime cumulative lifting load (Newton-hr)			n	disc protrusion at lower disc level (L45-S1)
				AOR
Only lift load above 4000 N was included	Low	0	254	1
	Intermediate	$0\sim< 2.0\times10^{6}$	24	0.7 (0.2-1.9)
	High	$\geq 2.0\times10^{6}$	23	2.6* (1.0-6.2)
Only lift load above 3400 N was included	Low	0	206	1
	Intermediate	$0\sim< 2.5\times10^{6}$	47	1.6 (0.7-3.4)
	High	$\geq 2.5\times10^{6}$	48	1.9 (0.9-3.9)
Only lift load above 2800 N was included	Low	0	142	1
	Intermediate	$0\sim< 1.8\times10^{6}$	79	1.9 (0.9-3.7)
	High	$\geq 1.8\times10^{6}$	80	2.7** (1.4-5.4)
lift load above 0 N was included	Low	$< 1.26\times10^{5}$	99	1
	Intermediate	$1.26\times10^{5}\sim< 5.6\times10^{6}$	101	2.0 (1.0-4.1)
	High	$\geq 5.6\times10^{6}$	101	2.3* (1.1-4.8)

Adjusted for age, BMI, smoking

Statistically significant: *, P<.05; **, P<.01; ***, P<.001.

Part III. Prediction of Lumbar Disc Bulging or Protrusion Based on Anthropometric Factors and Disc Morphology

Table 1. Demographic characteristics of the study participants (n=452)

Variables	N (%)
Age, mean ± SD (years)	49.3 ± 10.5
< 40	88 (19.5)
40~<50	10 (24.3)
50~<60	188 (41.6)
≥ 60	66 (14.6)
Gender	
Male/Female	210 (46.5) /242(53.5)
Body height, mean ± SD (cm)	162.8 ± 7.9
Body weight, mean ± SD (kg)	65.5 ± 11.6
BMI, mean ± SD (kg/m^2)	24.6 ± 3.6
< 24	191 (42.3)
24~<27	159 (35.2)
≥ 27	102 (22.6)

BMI, body mass index; SD, standard deviation

Table 2. The disc morphology factors of the L3-L4, L4-L5, and L5-S1 levels

Disc level	Disc height, mean ± SD (mm)	Disc depth, mean ± SD (mm)
L3-L4	8.2 ± 1.3	31.3 ± 2.7
L4-L5	9.3 ± 1.4	30.8 ± 2.7
L5-S1	8.9 ± 1.8	29.0 ± 2.6

Table 3. Intrareader reliability of disc bulging/protrusion in MRI by percentage agreement

	Disc level	Interreader reliability
Disc bulging or protrusion	L3-L4	0.883
	L4-L5	0.833
	L5-S1	0.883

Table 4. Intrareader and interreader reliability of disc height and disc depth measurement by interclass correlation coefficients (ICC)

	Disc level	Interreader reliability	Intrareader reliability
Disc height	L3-L4	0.878	0.917
	L4-L5	0.899	0.916
	L5-S1	0.943	0.948
Disc depth	L3-L4	0.805	0.926
	L4-L5	0.939	0.963
	L5-S1	0.858	0.991

Table 5. The association between anthropometric factors and disc bulging or protrusion, and anthropometric factors with disc morphology and disc bulging or protrusion at the L3-L4, L4-L5, and L5-S1 levels by logistic regression

	L3-L4 disc bulging/protrusion		L4-L5 disc bulging/protrusion		L5-S1 disc bulging/protrusion	
	Parameter Estimate (β)	P	Parameter Estimate (β)	P	Parameter Estimate (β)	P
Model 1						
Age	0.10	< 0.0001	0.01	< 0.0001	0.04	< 0.0001
Gender	-0.29	0.08	0.16	0.13	-0.04	0.8
Body height (cm)	-0.01	0.58	0.02	0.55	0.01	0.56
Body weight (kg)	0.04	0.0025	0.01	0.003	0.02	0.03
Model 2						
Age	0.08	< 0.0001	0.06	< 0.0001	0.04	0.0008
Gender	-0.10	0.59	-0.007	0.97	0.15	0.36
Body height (cm)	-0.05	0.02	-0.05	0.04	-0.005	0.82
Body weight (kg)	0.03	0.02	0.03	0.01	0.02	0.036
Disc height (mm)	-0.19	0.038	-0.18	0.03	-0.12	0.046
Disc depth (mm)	0.37	< 0.0001	0.30	< 0.0001	0.19	0.0009

List of Figures

Part I. Dose-Response Relationship between Lumbar Disc Degeneration and Life Time Cumulative Lifting Load

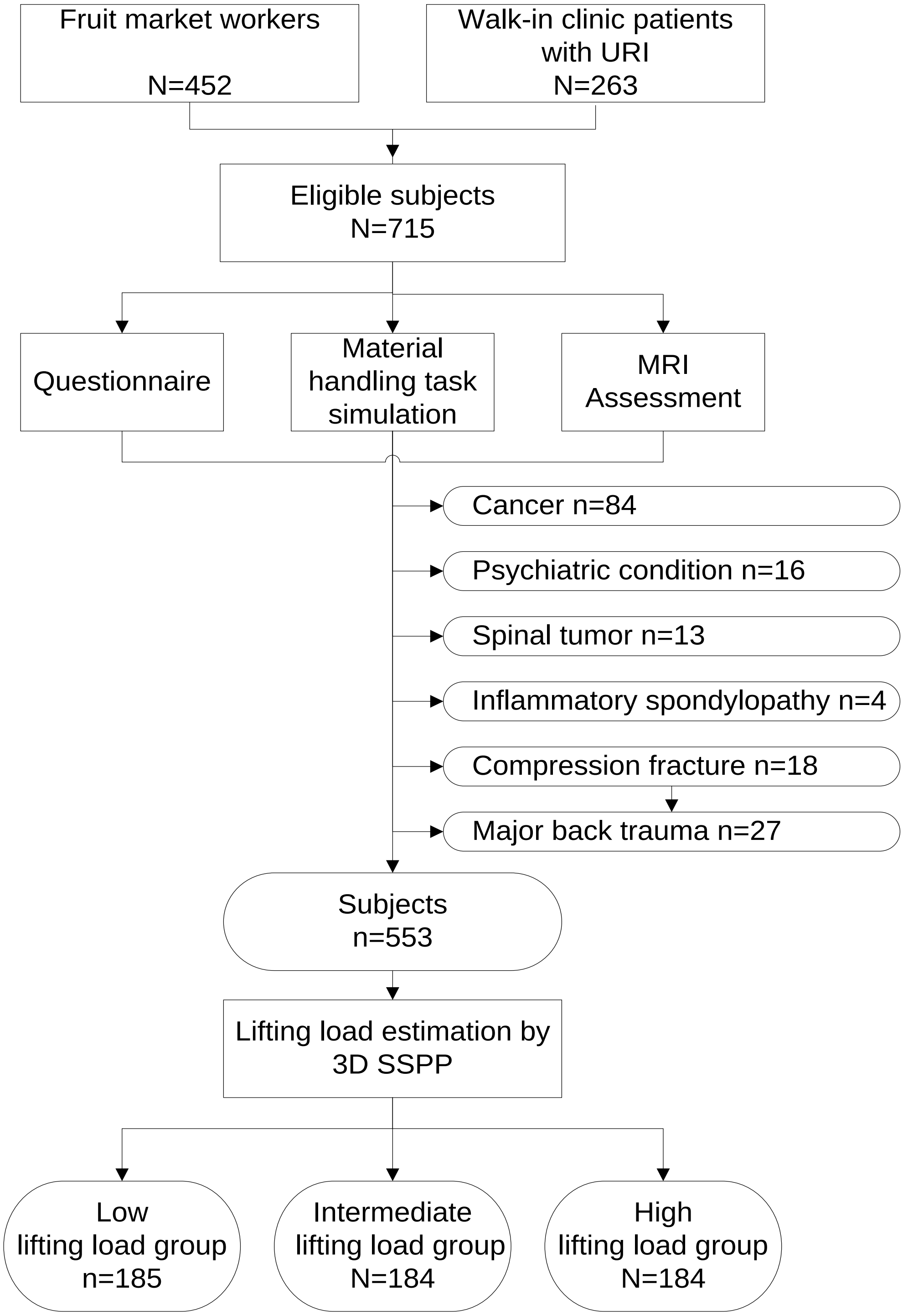


Figure1. Flow diagram of the participants selection process in the study

Part II. Threshold Values of Lumbar Load in Lifting for Calculating Lifetime Cumulative Load to Predict Disc Protrusion

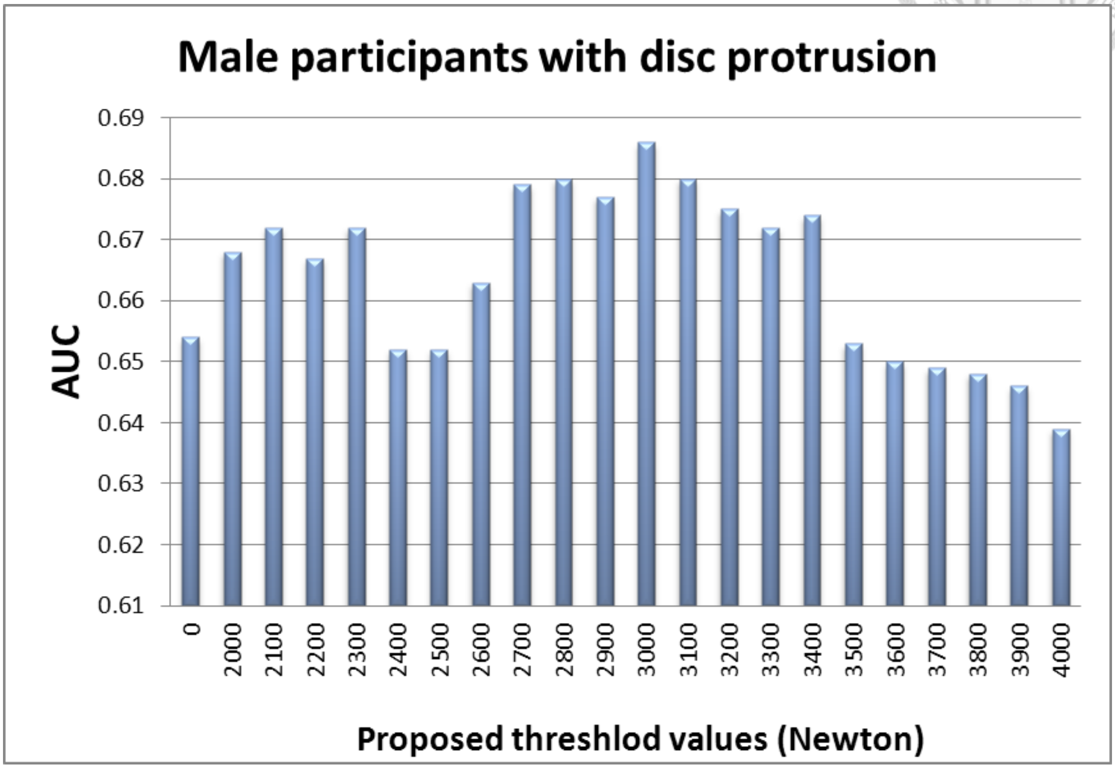


Figure 1 (a). The AUC statistic distrubution of L4-S1 disc protrusion with proposed threshold values in male participants

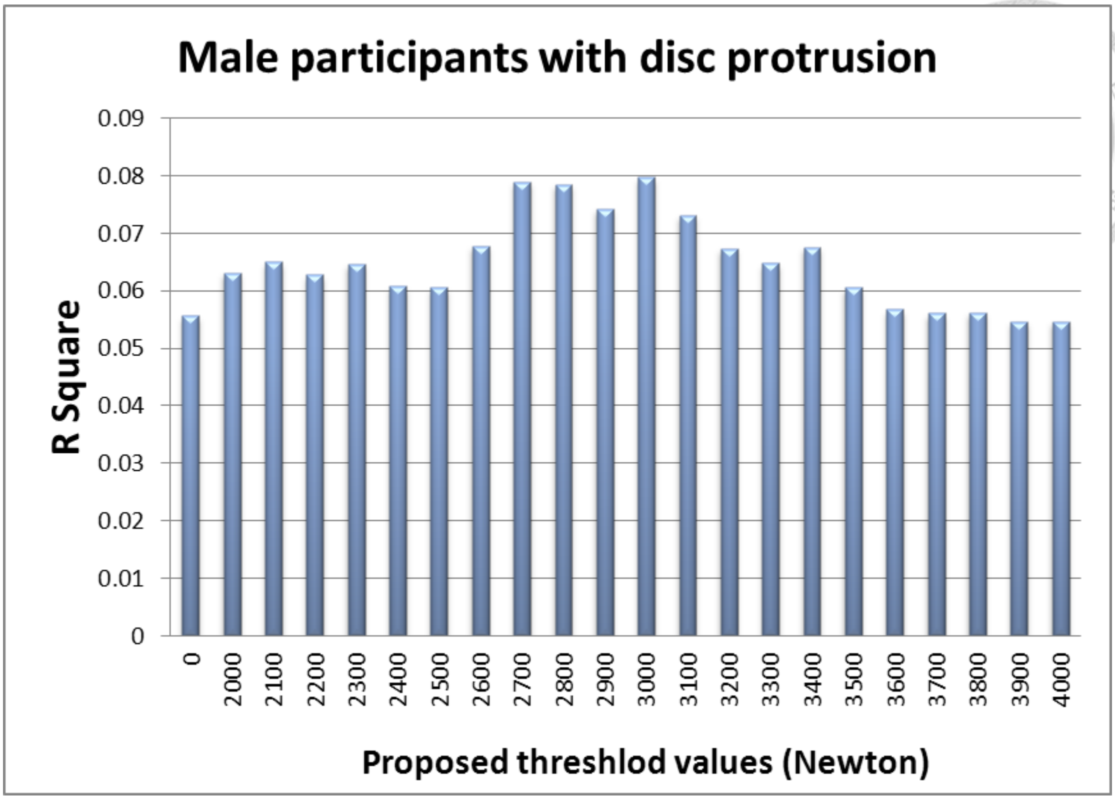


Figure 1 (b). The R Square values of L4-S1 disc protrusion with proposed threshold values in male participants

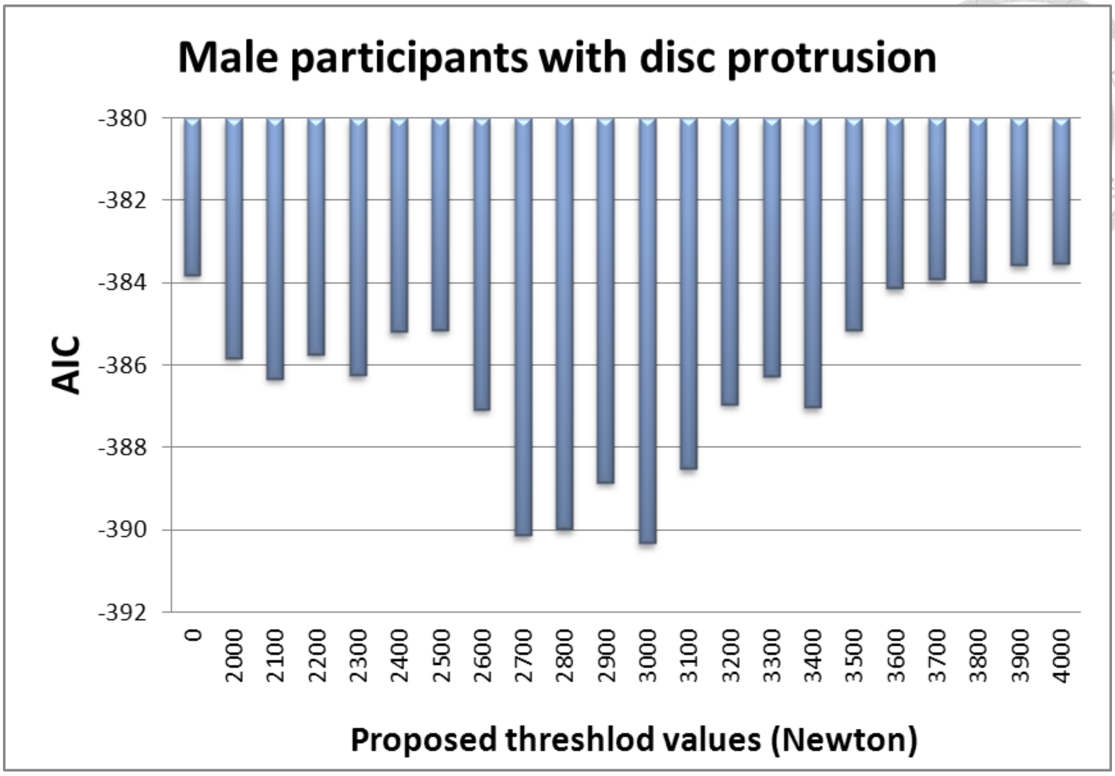


Figure 1 (c). The AIC values of L4-S1 disc protrusion with proposed threshold values in male participants

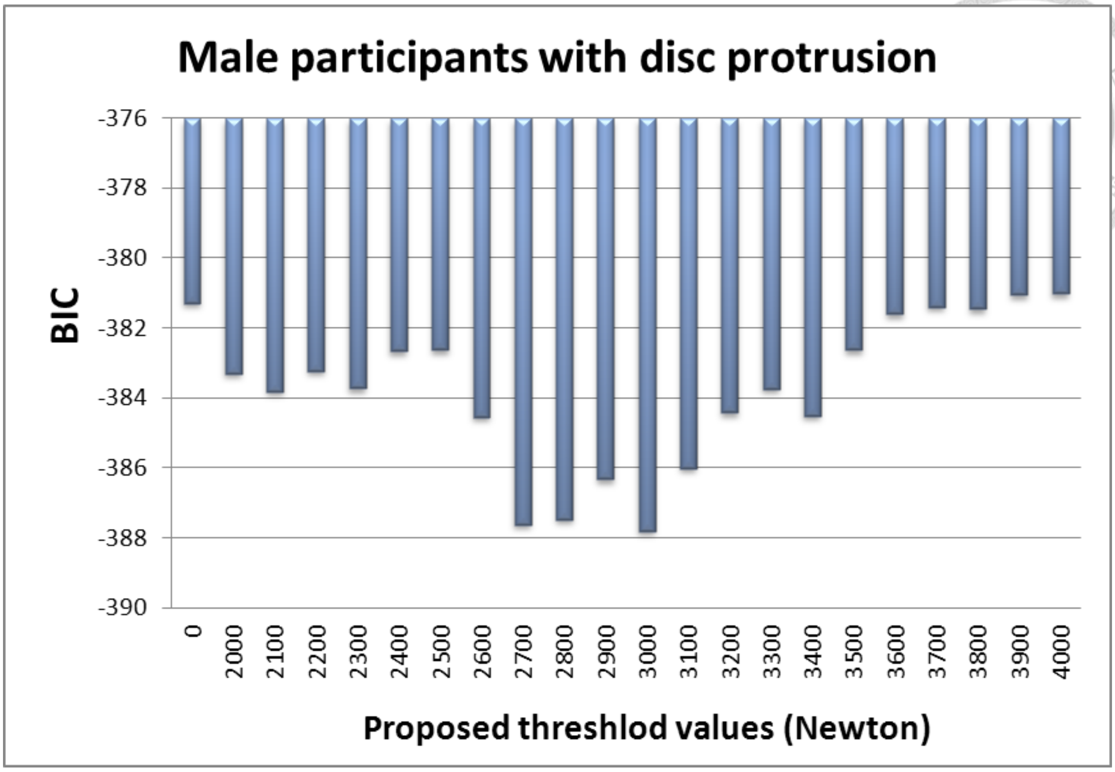


Figure 1 (d). The BIC values of L4-S1 disc protrusion with proposed threshold values in male participants

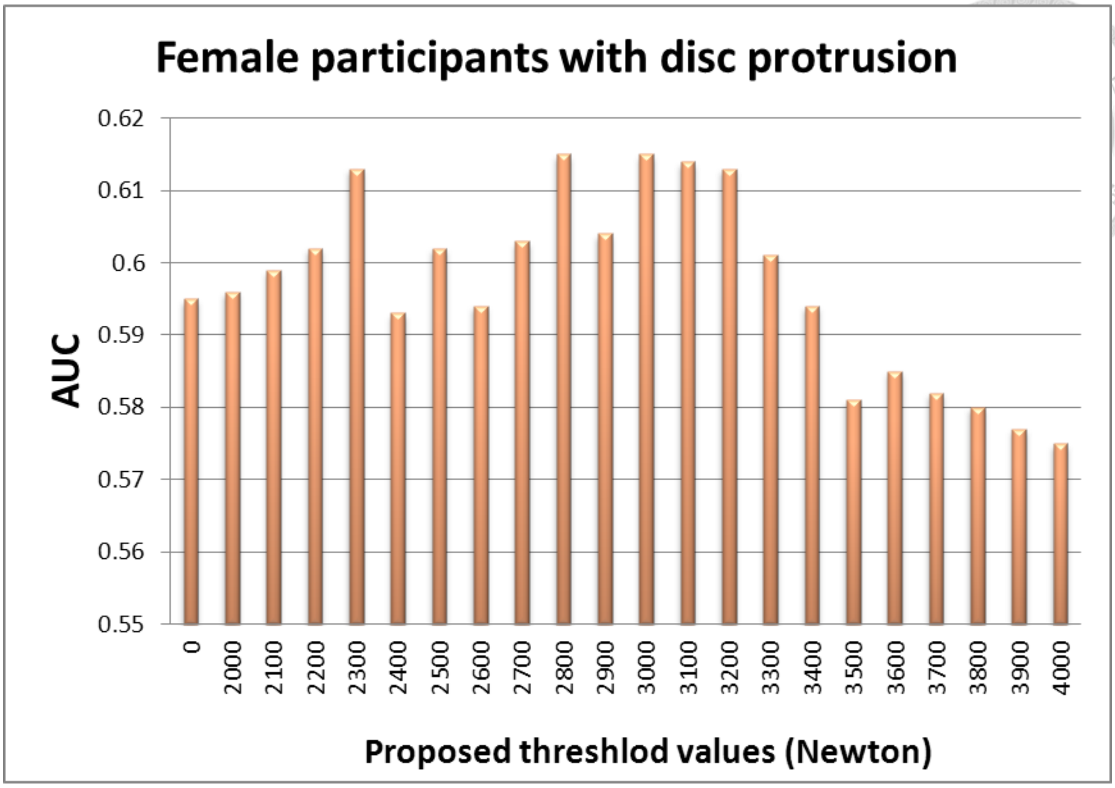


Figure 2 (a). The AUC statistic distrubution of L4-S1 disc protrusion with proposed threshold values in female participants

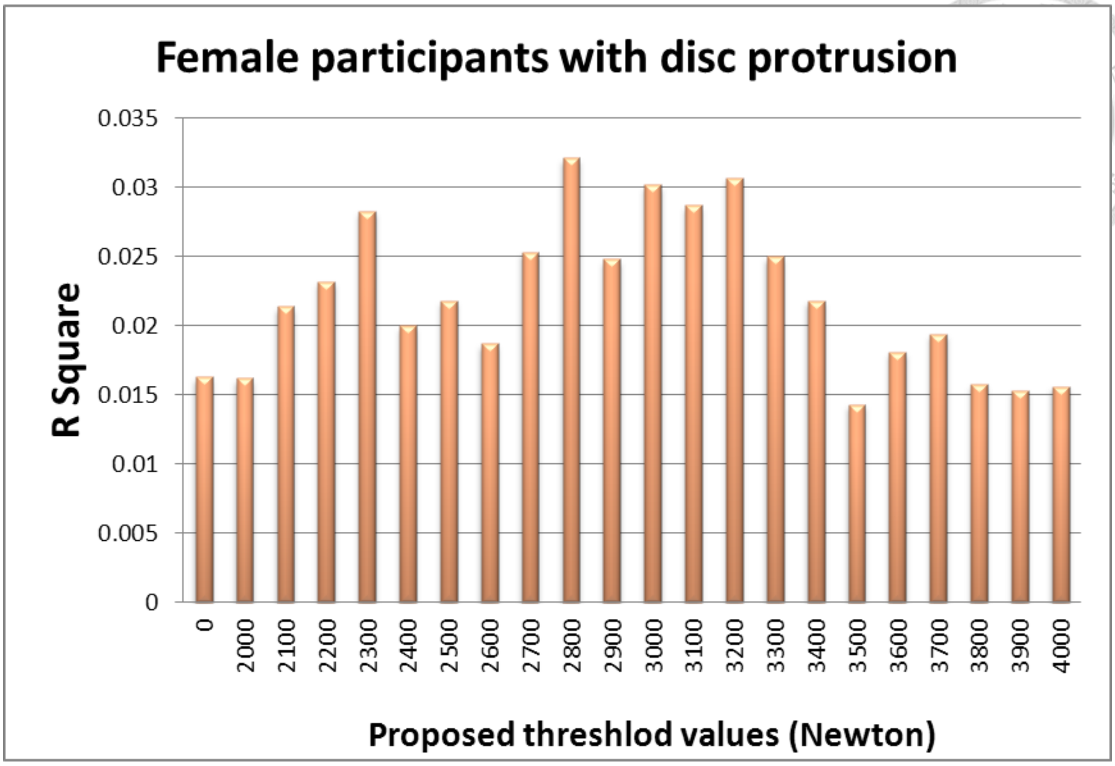


Figure 2 (b). The R Square values of L4-S1 disc protrusion with proposed threshold values in female participants

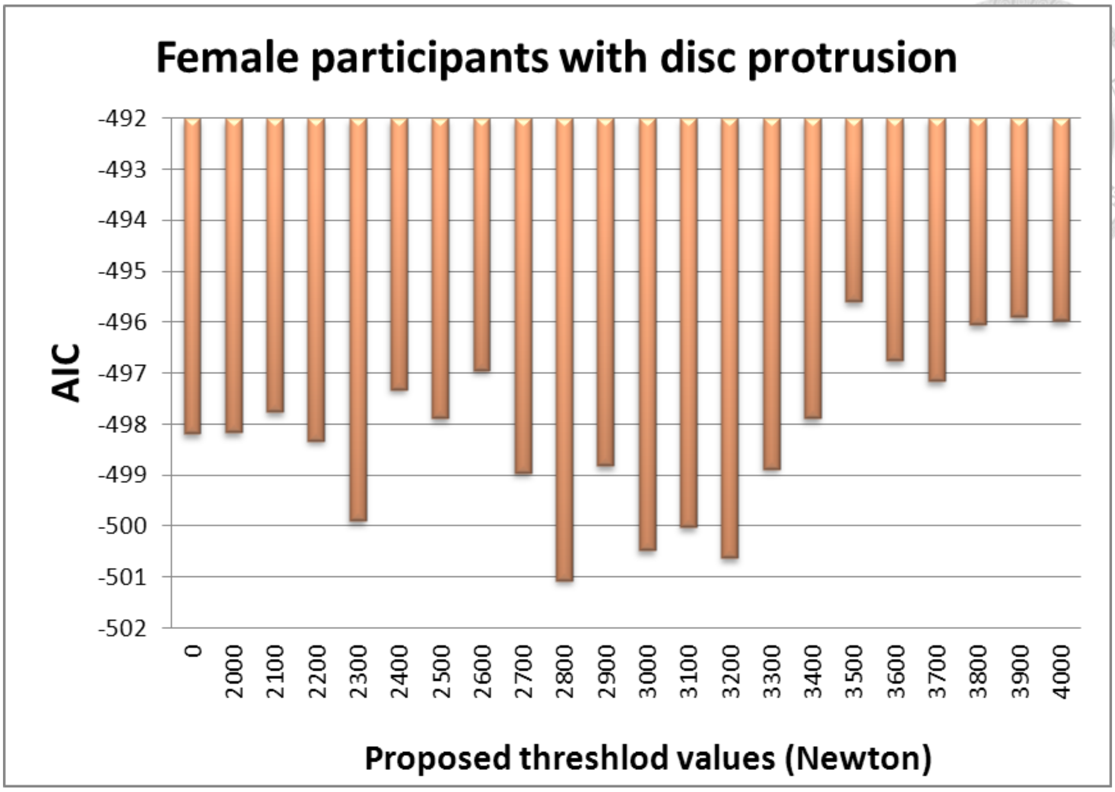


Figure 2 (c). The AIC values of L4-S1 disc protrusion with proposed threshold values in female participants

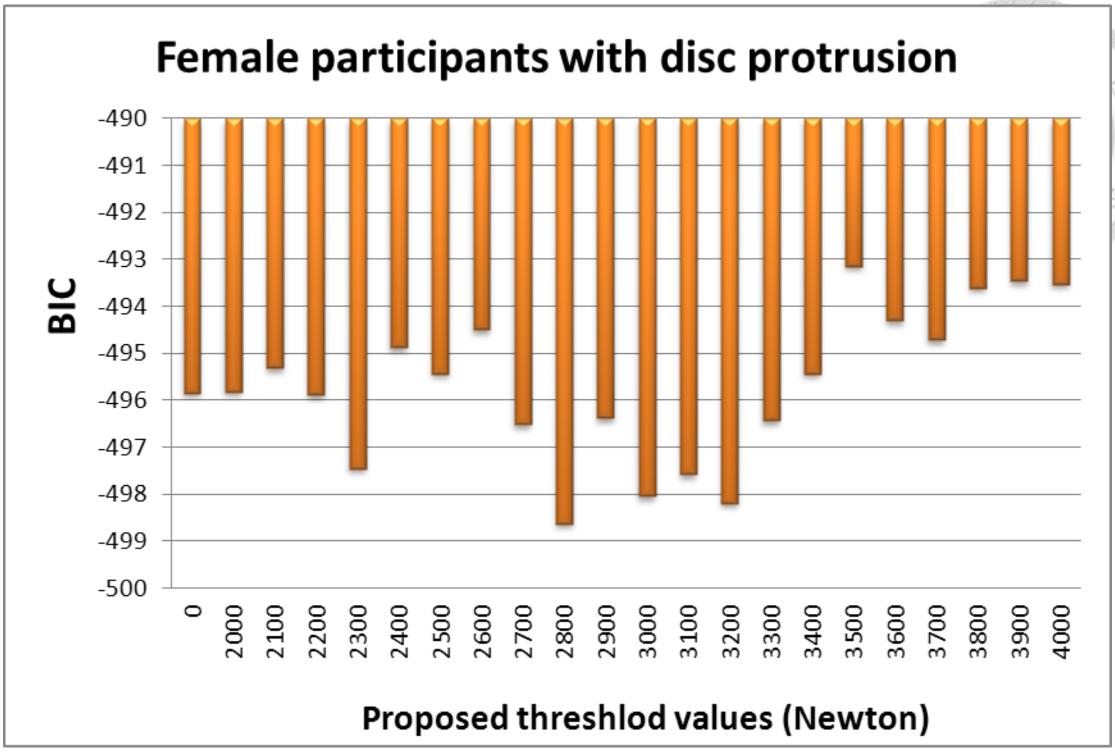


Figure 2 (d). The BIC values of L4-S1 disc protrusion with proposed threshold values in female participants

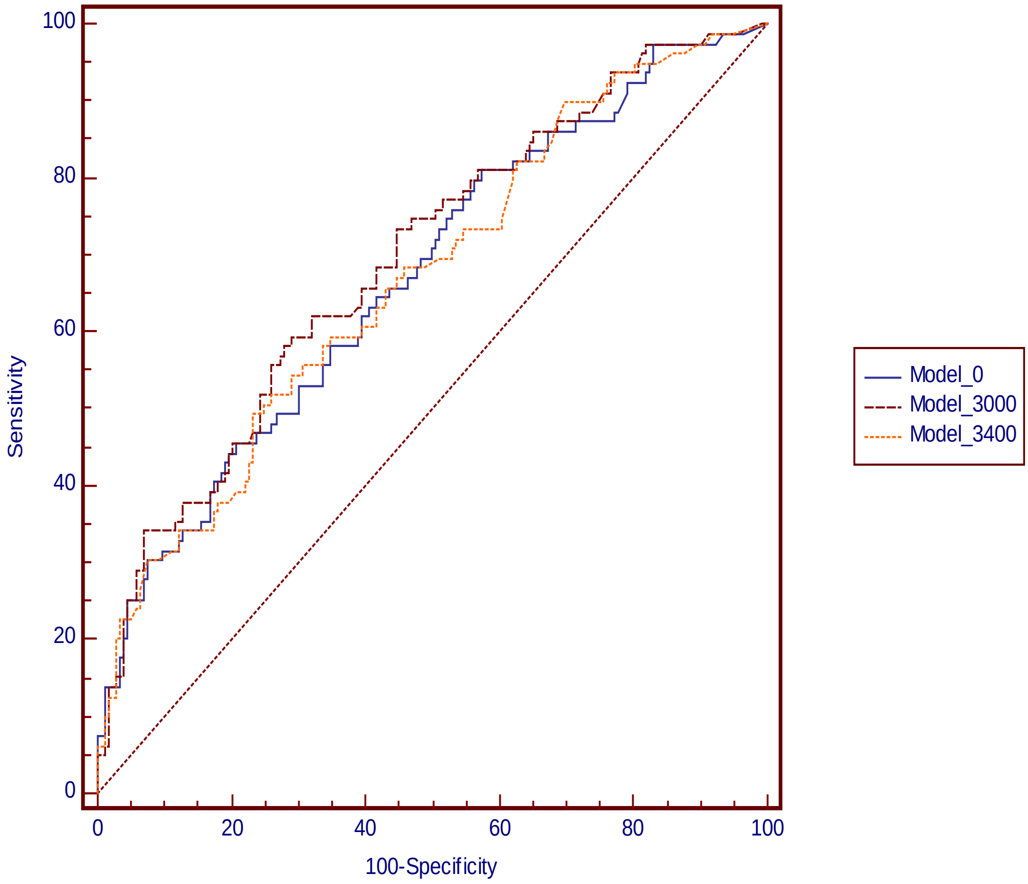


Figure 3. Receiver-operating characteristic curves for the prediction of L4-S1 disc protrusion in male participants by models of different threshold of lifting load.

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

Pairwise comparison of ROC curves
p-value for comparison of AUCs for Model 0 and Model 3000 = 0.149
p-value for comparison of AUCs for Model 3000 and Model 3400 = 0.155
p-value for comparison of AUCs for Model 3400 and Model 0 = 0.912

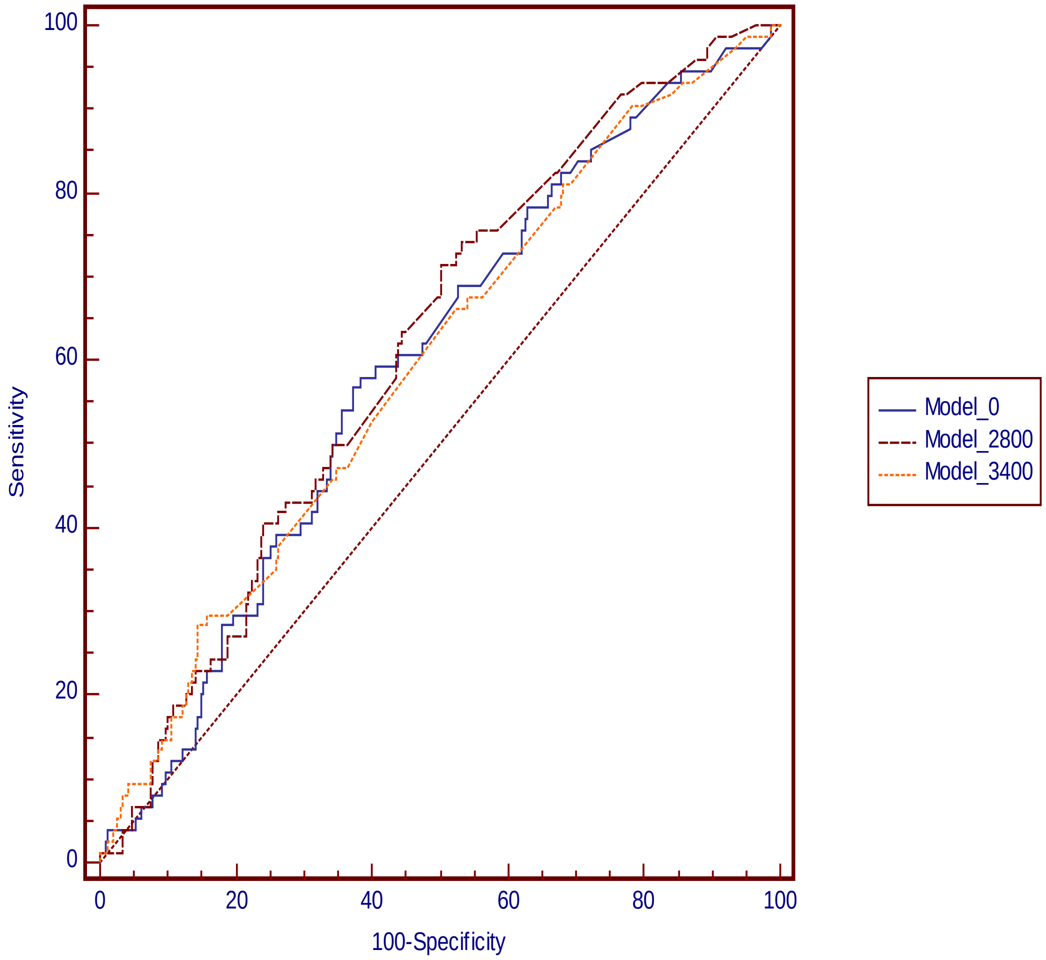


Figure 4. Receiver-operating characteristic curves for the prediction of L4-S1disc protrusion in female participants by models of different threshold of lifting load.

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

Pairwise comparison of ROC curves
p-value for comparison of AUCs for Model 0 and Model 2800 = 0.465
p-value for comparison of AUCs for Model 2800 and Model 3400 = 0.502
p-value for comparison of AUCs for Model 3400 and Model 0 = 0.988

Part III.Prediction of Lumbar Disc Bulging or Protrusion Based on Anthropometric Factors and Disc Morphology

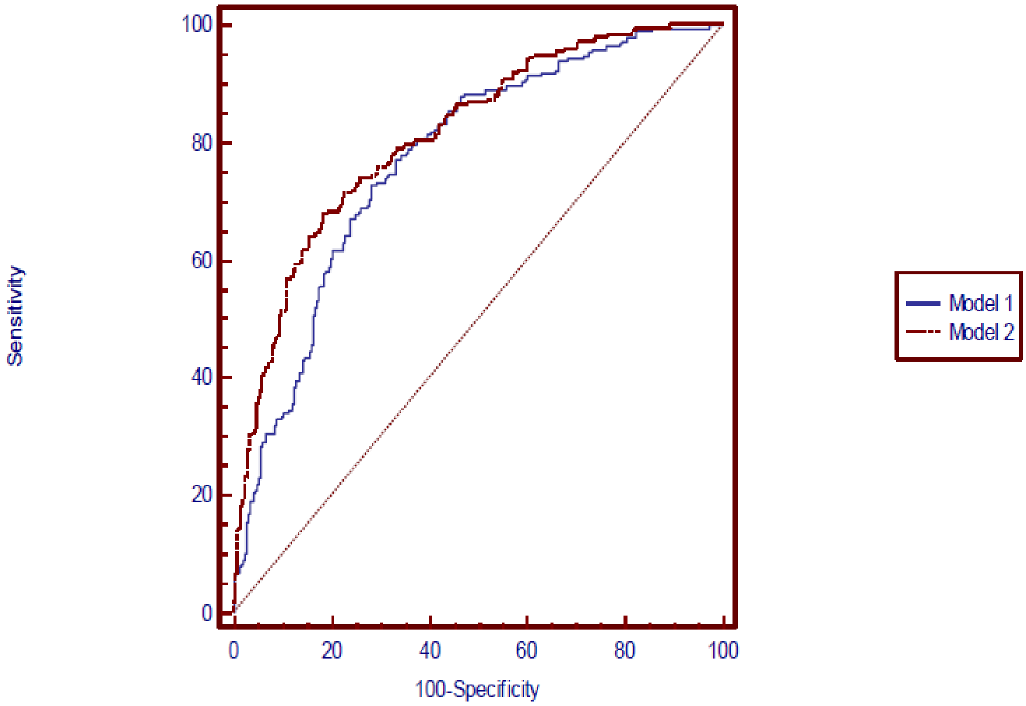


Figure 1. Receiver-operating characteristic curves for the prediction of L3-L4 disc bulging/protrusion by model 1 and model 2

Model 1: AUC (95% CI) = 0.77 (0.73 – 0.81). P = 0.0001*
Model 2: AUC (95% CI) = 0.81 (0.77 – 0.85). P = 0.0001*
p-value for comparison of AUCs < 0.05

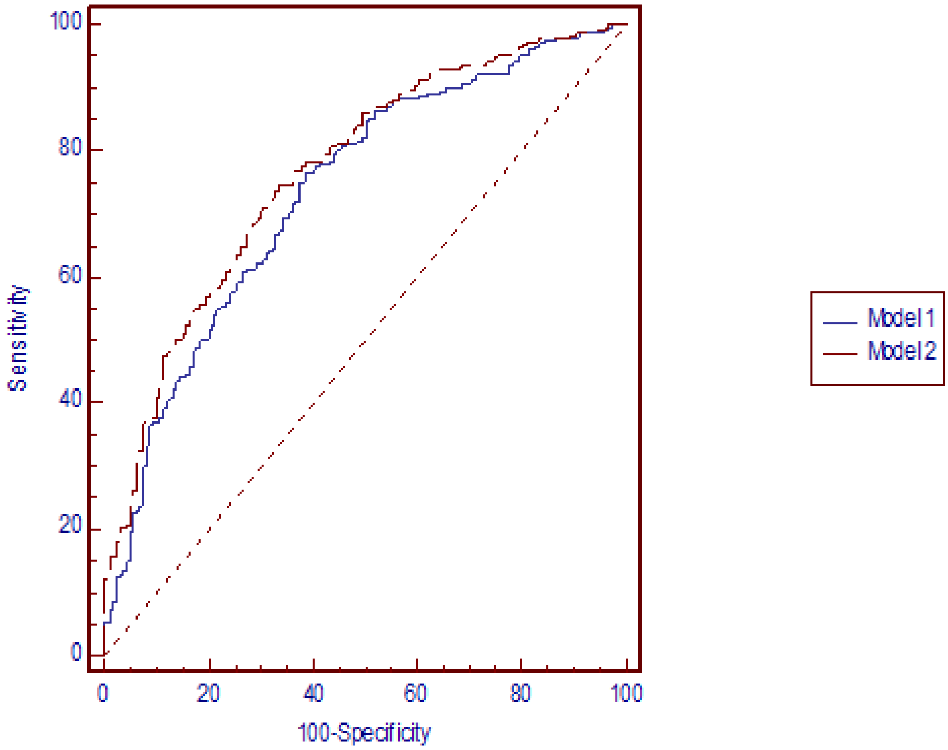


Figure 2. Receiver-operating characteristic curves for the prediction of L4-L5 disc bulging/protrusion by model 1 and model 2

Model 1: AUC (95% CI) = 0.74 (0.70 - 0.78). P = 0.0001*
Model 2: AUC (95% CI) = 0.77 (0.73 - 0.81). P= 0.0001*
p-value for comparison of AUCs < 0.05

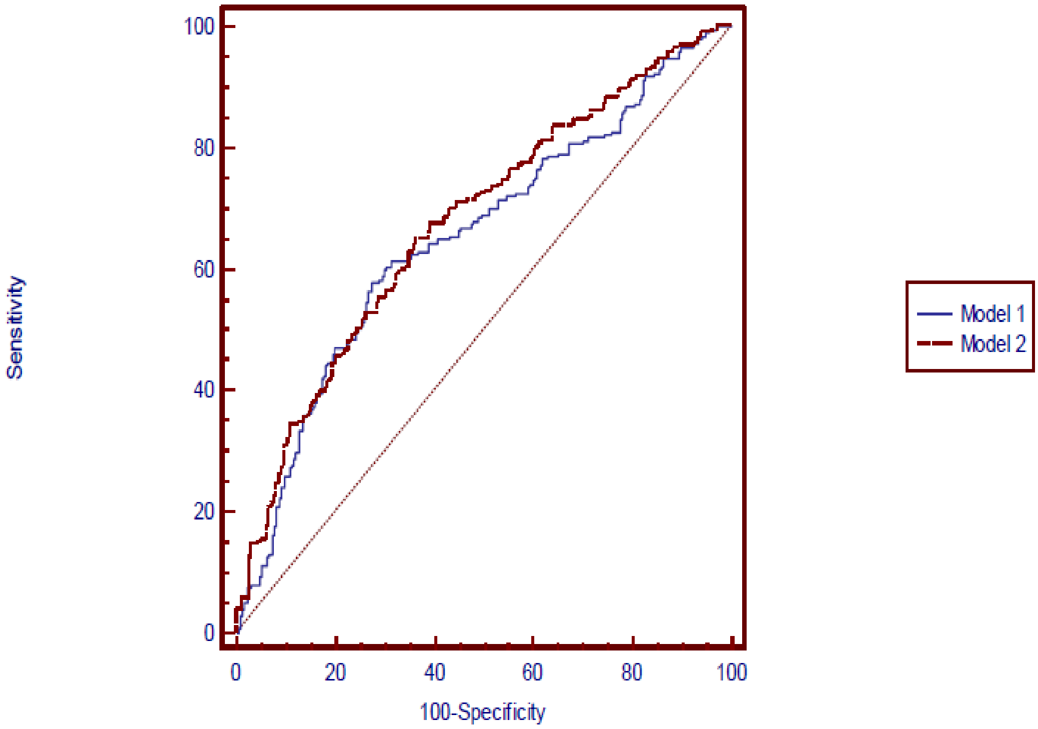


Figure 3. Receiver-operating characteristic curves for the prediction of L5-S1 disc bulging/protrusion by model 1 and model 2.

Model 1: AUC (95% CI) = 0.65 (0.61 – 0.70). P = 0.0001*
Model 2: AUC (95% CI) = 0.67 (0.63 – 0.72). P = 0.0001*
p-value for comparison of AUCs > 0.05

Appendix

流水編號：

臺灣地區下背痛調查問卷

您好！

這份問卷是評估造成下背痛的各項因子。您所提供的寶貴資料，將有助於了解下背痛之病因，與尋求解決與預防之方法。您是我們抽樣的對象，誠心請您能配合填寫此問卷，所有資料將僅用於統計分析，內容絕對保密，不另做他用，請您放心填寫，謝謝您的配合。

敬祝您　身體健康、工作愉快！

臺大醫院環境及職業醫學部郭育良教授

(2008/9/1)

第一部分：基本資料與健康狀況

姓名 ：______________　性別 ：□男　□女

聯絡方式(白天)：電話 ：_____________ 行動電話 ：________________

出生年月日：民國 ______年 _____月 _______日

年齡 ：____ 歲　身高：_________ 公分　體重：________公斤

教育程度：　□小學或以下　□國中　□高中職　□專科　□大學　□研究所

婚姻狀況：　□未婚　□已婚　□離婚或分居　□鰥寡

育有子女數：□無　□一人　□二人　□三人　□四人或以上

若您是女性，您是否曾經懷孕？□沒有 □有，懷孕____次，出生____人

1. 請您回想一下，從上了國中(12歲)之後，有沒有什麼運動是您每個禮拜都會參加的?（**連續3個月以上每周至少運動一次超過30分鐘、有流汗及心跳加速的才須紀錄**）

	運動-1	運動-2	運動-3	運動-4	運動-5
運動項目名稱					
一星期的次數					
持續時間	年 月	年 月	年 月	年 月	年 月
持續月份(免填)					

2. 我現在想請教您有關抽菸習慣的問題(**連續6個月以上,每日至少抽菸一支才須紀錄**)

(1)請問您有抽菸習慣嗎？□沒有（跳至第3題） □有 □曾有 ，民國____年戒掉(至少戒掉一年)

(2)總共抽了幾年？_____年(從_____歲開始到_____歲)

(3)在您抽煙的那幾年間， 平均每天抽_____支香煙

3. 我現在想請教您有關喝酒習慣的問題(**連續6個月以上，每周至少飲酒一次才須紀錄**)

(1) 請問您是否有喝酒的習慣? □沒有(跳至第4題) □有

□ 曾有，民國_____年戒掉(至少戒掉一年)

(2) 請問您喝酒習慣共約___年?(從____歲開始至____歲)

(3) 通常都喝哪一種酒?(請填寫下表)

種類	酒精濃度	酒杯代碼	每週次數	每次杯數
啤酒	3.5~4.5%			
水果酒:紅、白葡萄酒、玫瑰紅	10~12%			
花雕、紹興、烏梅、米酒	16~22%			
五加皮、竹葉青、白蘭地、威士忌、高梁、茅臺酒等	35~65%			
酒杯代碼：(1)20cc 高梁酒杯 (2)80cc 米酒杯 (3)120cc 葡萄酒杯 (4)360cc/罐 (5)600cc/瓶				

4. 我現在想請教您有關喝茶習慣的問題(**連續6個月以上，每個月至少喝兩次才須紀錄**）

（1）請問您是否有喝茶的習慣？□沒有(跳至第6題） □有

□ 曾有，民國_____年戒掉(至少戒掉一年）

（2）請問您喝茶習慣共約___年？（從____歲開始至____歲）

（3）通常都喝哪一種茶？

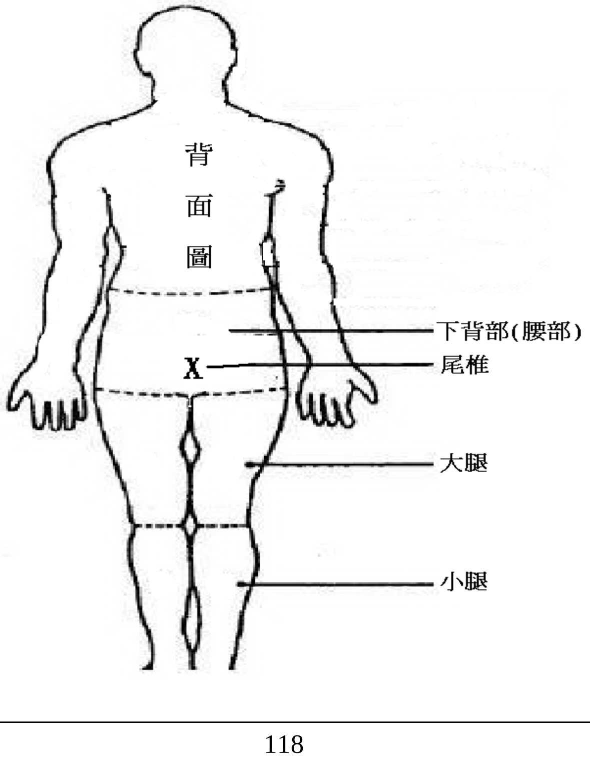
種類	每週次數	每次 c.c. 量
紅茶類		
綠茶類		
烏龍茶類、鐵觀音		

5. 請勾選以下符合您在食物以外維他命攝取的情形(**至少持續一年以上才須紀錄**)

	（1）幾乎不吃	（2）每周 1-6 次	（3）每天 1-2 次	（4）每天 3 次以上	持續服用時間	持續月份（免填）
綜合維他命					年 月	
維生素 A					年 月	
維生素 C					年 月	

第二部分：下背痛資料

1	請問您是否曾經有過下背痛?	□沒有，從來沒有 **（請跳至第三部分繼續作答）** □有，最早的一次是在幾歲?__歲
2	請問您是否曾經因為外傷(包括工作、運動或交通事故）而引起腰部受傷?	□沒有 □有
3	請問您有沒有動過腰部手術?	□沒有 □有，民國_____年_____月 診斷病因:____________
4	請問您最近一次下背疼痛是多久前的事了?	□上星期 □1 個月前 □3 個月前 □6 個月前 □超過 1 年以上
5	請問您最近一次的背痛為	□首次發生 □重覆發生
6	請問您**這一年來**，下背痛**疼痛的總天數**大約是?	□ 這一年來無下背痛 □ 不超過 1 週 □ 1 週~1 個月 □ 1~3 個月 □ 3~6 個月 □ 超過 6 個月
7	請問每次疼痛的**持續時間**大約多久?(每次疼痛的時間多長)	□不超過 1 天 □1-3 天 □3-7 天 □1-4 週 □1-3 個月 □>3個月
8	下列那種動作會加重您的背痛？(可複選)	□咳嗽 □上樓梯 □下樓梯

		□長時間坐 □向前彎腰 □向後彎腰 □持續站立 /轉身/走路 □其他，請列明：____________
9	背痛時，臥床休息能否減輕疼痛？	□可以減輕痛楚 □疼痛無改變 □不能，痛楚反而加劇
10	那種方法能減輕疼痛？(可複選)	□止痛藥 □熱敷 □運動 □休息 □沒有方法 □其他，請列明：____________
11	請在下方橫線上用 **‘X’** 顯示你現在這次下背疼痛痛楚的程度： 完全不痛 0---1---2---3---4---5---6---7---8---9---10 痛到無法忍受	
12	請依據附圖勾選您不舒服(酸、痛、痳)的部位 **(如無此徵狀，不用作答此題)** 	

			症狀					
			酸		**痛**		**麻**	
部位	**下背部**	左邊						
		中間						
		右邊						
	尾椎							
			左	**右**	**左**	**右**	**左**	**右**
	大腿	前面						
		旁邊						
		後面						
	小腿	前面						
		旁邊						
		後面						
	腳部	腳背或腳底						
		外側緣或第五趾						

13	請問您現在有沒有**下肢無力**的情形？ **（如無此徵狀，不用作答此題）**	□沒有 □左邊下肢無力 □右邊下肢無力 □兩邊下肢無力
14	您現在走路時有沒有困難？ **（如無此徵狀，不用作答此題）**	□沒有 □有，因為痛楚，難以開始步行 □有，因為雙腳僵硬緊張，難以起步 □有，因持續步行後下肢疼痛（或無力或麻痺 □有，因為其他原因 （請列明： ）
15	您現在能否持續走路或站立？	□能，（ ）分鐘 □不能，剛開始時背或腳已很疼痛 □不能，剛開始時沒問題，之後背痛更嚴重 □不能，剛開始時沒問題，

		之後臀/腳痛更嚴重 □不能，剛開始時沒問題，之後臀/腳麻痺更嚴重 □不能，因為其他原因（請列明：　　）
16	在持續走路或站立時，如果向前彎腰，您的疼痛(背、臀或腳痛或麻痺等徵狀)能能否減輕？	□能 □不能，疼痛無改變 □不能，背痛加劇 □不能，腳痛 / 麻痺反而更嚴重
17	在您持續走路或站立後，當出現背、臀、腳痛或麻痺加劇等，如果坐下來休息能否使徵狀舒緩？	□能 □不能，疼痛無改變 □不能，背痛更嚴重 □不能，腳痛 / 麻痺反而更嚴重
18	您現在有否大小便問題？	□沒有 □小便困難 □小便失禁 □大便失禁

22.下背痛生活障礙問卷(**以最近半年之情形作答**)

1	□是　□否	因為腰背部不舒服，大部分時間我都在家裡。
2	□是　□否	我常改變姿勢，試著讓我的腰背部舒服。
3	□是　□否	因為腰背部不舒服，我走路比平常慢。
4	□是　□否	因為腰背部不舒服，現在我不做平時我會做的家務。
5	□是　□否	因為腰背部不舒服，我會扶著樓梯扶手上樓。
6	□是　□否	因為腰背部不舒服，我經常躺下來休息。
7	□是　□否	因為腰背部不舒服,我必須扶著些什麼才能從有扶手的椅子上起身。
8	□是　□否	因為腰背部不舒服，我試著找別人來為我做事。
9	□是　□否	因為腰背部不舒服，我穿衣服比平常慢。
10	□是　□否	因為腰背部不舒服，我不能久站。
11	□是　□否	因為腰背部不舒服，我盡可能不彎腰也不跪著。
12	□是　□否	因為腰背部不舒服，我覺得從椅子上起身有困難。
13	□是　□否	我的腰背幾乎隨時都在痛。
14	□是　□否	因為腰背部不舒服，我覺得在床上翻身有困難。
15	□是　□否	因為腰背部痛，我的胃口不太好。
16	□是　□否	因為腰背部痛，我穿襪子有困難。
17	□是　□否	因為腰背部痛，我只能走短程的路。
18	□是　□否	因為腰背部不舒服，我睡的比較不好。
19	□是　□否	因為腰背部不舒服，一天之中大部分時間我都坐著。
20	□是　□否	因為腰背部痛，我穿衣服要靠別人幫忙。
21	□是　□否	因為腰背部不舒服，我避免做家中粗重的工作。
22	□是　□否	因為腰背部不舒服，我對人變得比平常較暴躁易怒。
23	□是　□否	因為腰背部不舒服，我上樓比平常慢。
24	□是　□否	因為腰背部不舒服，大部分時間我都留在床上。

第三部分：交通工具使用調查

1. 請問您平時必須乘坐/駕駛的車種及平均時間為?

		車種代號	平均時間(**小時/天**)	駕駛年數
工作中	(1)			
	(2)			
	(3)			
工作以外(包括通勤)	(1)			
	(2)			
	(3)			

(1)機車 (2)汽車 (3)公車/客運 (4)捷運 (5)火車 (6)小貨車 (7)貨運卡車 (8)拖車 (9)垃圾車 (10)堆高機 (11)起重機 (12) 鐵輪壓路機 (13)混凝土破壞機(14)曳引貨櫃車 (15)砂石車 (16)油罐車 (17)腳踏車

(18)其他---請自行填入到車種代號空格中

第四部分：職業與工作內容描述(僅列超過六個月的工作)

<table>
<tr><td></td><td colspan="3">工作一</td><td colspan="3">工作二</td><td colspan="3">工作三</td><td colspan="3">工作四</td></tr>
<tr><td>事業別</td><td colspan="3"></td><td colspan="3"></td><td colspan="3"></td><td colspan="3"></td></tr>
<tr><td>職稱</td><td colspan="3"></td><td colspan="3"></td><td colspan="3"></td><td colspan="3"></td></tr>
<tr><td>工作年資</td><td colspan="3">年 月</td><td colspan="3">年
月</td><td colspan="3">年 月</td><td colspan="3">年 月</td></tr>
<tr><td>持續月份</td><td colspan="3"></td><td colspan="3"></td><td colspan="3"></td><td colspan="3"></td></tr>
<tr><td>當時體重</td><td colspan="3">公斤</td><td colspan="3">公斤</td><td colspan="3">公斤</td><td colspan="3">公斤</td></tr>
<tr><td>每周工作天數</td><td colspan="3"></td><td colspan="3"></td><td colspan="3"></td><td colspan="3"></td></tr>
<tr><td>工作內容簡述</td><td colspan="3"></td><td colspan="3"></td><td colspan="3"></td><td colspan="3"></td></tr>
<tr><td>搬運重量（公斤）</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>搬運頻率（次/天）</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>搬運抬舉時間（秒/次）</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>抬舉受力（免填）</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>搬運走動時間（秒/次）</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>走動受力（免填）</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>搬運下貨時間（秒/次）</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>下貨受力（免填）</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>彎腰次數</td><td colspan="3"></td><td colspan="3"></td><td colspan="3"></td><td colspan="3"></td></tr>
</table>

（次/天）				
彎腰時間（分/天）				
坐(時/天）				
坐姿受力（免填）				
站(時/天）				
站**姿受力**（免填）				
工作體能需求分類				

請由下面表格選取符合您工作的描述

	分類	工作體能需求
A	坐	採坐姿工作，偶而也必須站立或走動，通常也需要攜帶物品(如 文件小於 5 公斤)但不超過 1/3 工作時間
B	輕度	大部份時間仍是坐著工作，有較長時間的站立和走動， 須搬運的重量在 10 公斤以下(不超過 1/3 工作時間)， 或 5 公斤以下(不超過 2/3 工作時間)。
	中度	搬運 10-23 公斤重物的時間不超過 1/3 工作時間 或搬運 5-12 公斤重物的時間不超過 2/3 工作時間 或超過 2/3 以上的工作時間 搬運小於 5 公斤的重物
D	重度	搬運 23-45 公斤重物的時間不超過 1/3 工作時間 或搬運 12-23 公斤重物的時間不超過 2/3 工作時間 或超過 2/3 以上的工作時間 搬運 5-10 公斤的重物
E	極重度	搬運 45 公斤以上重物的時間不超過 1/3 工作時間或 搬運 23 公斤以上重物的時間不超過 2/3　工作時間或 超過 2/3 以上的工作時間 搬運小於 10 公斤的重物

非常感激您的時間及寶貴的資料!