ORIGINAL ARTICLE

Occupational and personal factors associated with acquired lumbar spondylolisthesis of urban taxi drivers

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Aims: To investigate the occupational and personal factors associated with lumbar spondylolisthesis in taxi drivers.
Methods: Cross-sectional analysis of the baseline data from the Taxi Drivers' Health Study cohort. Information was retrieved from the medical records of standardised lumbosacral spine plain films, age, and anthropometric measures of 1242 subjects. Acquired spondylolisthesis (ASL) was defined as non-lytic spondylolisthesis involving lumbar spines above L5. Questionnaires were used to gather information on demographic features, health behaviours, exercise, work related physical and psychosocial factors, and driving time profiles. Multiple logistic regression was used to model the odds ratio (OR) for prevalent ASL cases associated with personal and occupational factors.
Results: A total of 40 cases (3.2%) of ASL were diagnosed. Among those driving $\leqslant$5 years, 6–15 years, and >15 years, the estimated prevalence of lumbar spondylolisthesis was 1.1%, 2.4%, and 7.1% respectively. Results of multiple logistic regression suggested that taxicab driving >15 years (OR = 3.4, 95% CI 1.1 to 10.7, compared to driving $\leqslant$5 years), age (OR = 2.6, 95% CI 1.1 to 6.6 for age 46–55; and OR = 4.8, 95% CI 1.8 to 12.9 for age >55), body mass index $\geqslant$25 kg/m^2 (OR = 2.2, 95% CI 1.1 to 4.6), and frequent strenuous exercise (OR = 2.2, 95% CI 1.1 to 4.5) were significantly associated with higher prevalence of spondylolisthesis. There was a consistent likely exposure-response relation between professional seniority and ASL prevalence.
Conclusions: Longitudinal studies are needed to confirm the observed association between professional driving and spondylolisthesis, and to examine further the specific occupational exposures accountable for this association.

First described by Herbineaux in the late 18th century,[1] lumbar spondylolisthesis remains a significant source of back pain and disability.[2] From the public health perspective, it would be desirable and potentially cost effective to slow the clinical course or even prevent the occurrence of this costly spinal disorder. However, most of our current knowledge about the causes of spondylolisthesis stems from descriptive radiographic and clinical observations. For instance, it has been found that abnormalities of the upper sacrum,[3] dysplasia of L5 neural arch,[4] and spina bifida[5] can predispose to slippage of vertebra. Hereditary susceptibility[5 6] has also been observed in certain types of spondylolisthesis, for example, the isthmic lytic type, which is the most prevalent spondylolisthesis among children and adolescents. Female predominance,[7] racial difference[7 8] in the frequency of spondylolisthesis, and sports injuries[9] in relation to subsequent development of spondylolisthesis are also reported. Additionally, anatomically defined factors, such as sagitally oriented facet joints,[10 11] increased pedicle-facet angle,[12] and horizontalisation of the lamina,[13] have been related to spondylolisthesis. Unfortunately, these putative biological risk factors for lumbar spondylolisthesis are generally not modifiable. To develop a better prevention strategy, we need more population based studies designed to investigate potentially modifiable factors, such as environmental or occupational factors.

A few previous occupational epidemiological findings drew our attention to spondylolisthesis among professional drivers. In a longitudinal observation of 211 young (mean age 17 years) tractor drivers,[14 15] investigators noted that the proportion of drivers with pathological changes of the spinal column increased from 57% in 1966 to 80% in 1971. Fisher and colleagues[16] compared radiographs of 136 helicopters and 143 jet pilots of comparable ages. They found that the degenerative changes of spine were more frequent among helicopter pilots (80%) than jet pilots (59%). Froom and colleagues[17] studied specifically spondylolisthesis among helicopter pilots and found that helicopter pilots had a four times higher prevalence of spondylolisthesis than the reference group (4.5% *v* 1%). However, these differences in prevalence of spondylolisthesis were based on univariable between-group comparison, which was likely subject to confounding by other factors related to spondylolisthesis, such as age and physical activities.

In the current epidemiological study, we aimed to examine the association of spondylolisthesis and professional seniority of taxi drivers. Using multivariable analyses, we attempted to identify personal characteristics, and occupational factors if any, associated with spondylolisthesis in professional taxi drivers. We hypothesised that the frequency of spondylolisthesis increases with taxi drivers' professional seniority.

METHODS

Study population

The study population was the baseline cohort of the Taxi Drivers' Health Study (TDHS),[18 19] which is an integrated part of a medical monitoring programme sponsored by the Taipei City Government to provide taxi drivers free physical examinations each year. From 31 January to 31 May 2000, 3295 taxi drivers participated in this programme. From five designated hospitals, we selected the one with the largest assigned service volume as the study base of TDHS. The main outcomes of research interest at the design phase of TDHS

Abbreviations: ASL, acquired spondylolisthesis; BMI, body mass index; CI, confidence interval; OR, odds ratio; TDHS, Taxi Drivers' Health Study

Main messages

- Little is known about potentially modifiable personal and environmental risk factors for lumbar spondylolisthesis.
- This epidemiological study provides the first results suggesting an association between acquired lumbar spondylolisthesis and taxi driving.
- Age, overweight and obesity, and frequent strenuous exercise, are all associated with increased prevalence of acquired lumbar spondylolisthesis.

Policy implications

- Longitudinal studies are needed to confirm the observed cross-sectional association between professional driving and lumbar spondylolisthesis, and further examine the specific occupational exposures accountable for this association.

included cardiovascular disease risks, job stress, and low back disorders, among others. For drivers to be eligible for enrolment in this study, they had to have been: (a) registered taxi drivers in Taipei City for at least one year; (b) willing to participate; and (c) able to read. The research protocols and consent forms were approved by the Human Subjects Committee of the Harvard School of Public Health, Boston, MA, USA, and by the Institutional Review Board of the Taipei Veterans General Hospital, Taipei, Taiwan. Informed consent was obtained from every TDHS participant in the selected hospital.

Outcome measures

Standardised anterior-posterior (AP) and lateral plain radiographs of lumbosacral spine were used in this medical monitoring programme to screen L-spine abnormalities. From the descriptive files of all radiological diagnoses of each study participant, we searched for the diagnosis of lumbar spondylolysis and spondylolisthesis, along with the levels of involvement. Acquired spondylolisthesis (ASL), which was the outcome of interest for the current study, was defined as radiographic spondylolisthesis without spondylolysis involving lumbar intervertebral levels above L5. This definition followed the classification scheme proposed by Marchetti and Bartolozzi.[20] We disregarded isthmic spondylolisthesis, because such developmental lesions very often (>85%) involve the lumbosacral level, and most have occurred before adulthood.[21 22] The presence of spondylolisthesis was defined as a translation of a vertebral body on the segment immediately below (fig 1), and the degree of translation was graded according to Meyerding's method.[23] All L-spine radiographs were interpreted by a single radiologist (WP Chan) experienced in spinal imaging. The reader was aware of the occupation of the study subjects but blind to their age, professional seniority, risk profiles for low back pain, and any clinical symptoms. The test-retest reliability assessment conducted in 2002 among a sample of 100 films (30 from taxi drivers with spondylolisthesis and 70 from other healthy subjects coming to medical examinations clinics) indicated a 100% agreement on the presence of spondylolisthesis.

Measurement of covariates

We developed a standardised self-administered instrument to measure personal characteristics and occupational factors in this study. The feasibility of this instrument was tested in a convenience sample of drivers before the study began. This instrument incorporated a modified Nordic Musculoskeletal Questionnaire (NMQ) that provided a graph of nine body parts and asked subjects to mark the anatomic site(s) where they ever suffered from any pain in the last 12 months. The NMQ has been documented to have acceptable validity and reliability.[24 25] Besides demographics features and health behaviours, the questionnaires consisted of items for driving time profiles (professional seniority in years, average days of driving per month, and daily driving duration in hours), and average frequency of physical activities (lifting task and bending/twisting) at work and during leisure time. The instrument also included the job dissatisfaction subscale of the Job Contents Questionnaire (Chinese version), and five questions from the Mental Health Index of the Taiwanese version of SF-36. Prior studies have found these two inventories to have good reliability and validity.[26 27] Age, anthropometric measures (body weight and height), and laboratory data were retrieved from the medical examination files.

Statistical analysis

We used multiple logistic regression to estimate the prevalence odds ratio (OR) of ASL associated with change in professional seniority. We grouped drivers into three categories according to the total years of taxi driving ($\leqslant$5, 6–15, and >15 years), and calculated the crude OR of ASL for each group, using the most junior drivers ($\leqslant$5 years) as the reference. In order to make statistical inference about effect of professional seniority on the ASL prevalence conditional on other predictors, established risk factors (age, gender, strenuous exercise) for spondylolisthesis were retained in every step of model building regardless of the significance

Figure 1 Lateral view of lumbar radiograph of a 47 year old male taxi driver showing a grade I spondylolisthesis of L4 on L5.

levels they reached in the crude univariate analyses. For any other variable to be included in logistic regression, it must have resulted in at least a 10% change in the estimate of the OR associated with professional seniority or be statistically significant at the 0.20 level in the univariate analysis. We assumed no interaction terms among potential predictors, and only included cases with complete data information in the final analyses. The Hosmer-Lemeshow test[28] was used to assess the goodness-of-fit. All of these statistical analyses were carried out by STATA 7.0 statistical software (STATA Corporation, College Station, TX).

RESULTS

During the study period for collecting baseline TDHS data, of the 1355 drivers receiving medical examinations in the selected hospital, 1351 had the reports of their L-spine radiographs available and 1242 (92%) completed the questionnaire. Table 1 shows personal characteristics and occupational factors of our study participants. Fifty one per cent (51%) reported low back pain in the past year. Compared to the other 1940 drivers who were not enrolled in TDHS but had received medical examinations in other hospitals, the TDHS enrolees were not systematically different from those who were not enrolled, with respect to the distribution of age, gender, professional seniority, daily driving duration, body mass index (BMI), marital status, and registration type. The demographic features of these two groups of drivers were also comparable to the reference statistics from a nationwide survey[29] on taxi drivers in 2000. In a small subset of TDHS baseline data from drivers who also participated in an exposure assessment study on whole body vibration, we found that self-reported professional seniority correlated very well with data obtained from the taxi drivers' registration records or through structured interviews (Pearson's correlation coefficient = 0.96). Although self-reporting on average underestimated professional seniority by 0.2 years, this measurement error is independent of having low back pain ($p = 0.73$) and also independent of the presence of lumbar spondylolisthesis ($p = 0.94$).

A total of 39 (3.2%) cases of non-lytic spondylolisthesis involving lumbar intervertebral levels above L5 were diagnosed; of these, 17 (44%) had associated with degenerative changes of their lumbar spines but none revealed radiographic evidence of prior back surgery. No moderate or advanced cases of spondylolisthesis were noted in the radiographic reports. Thirty four cases (87%) involved single level (including 14 at L4/L5, 14 at L3/L4, and 6 at L2/L3) while five (13%) involved two levels. One 48 year old male subject, having been a taxi driver for seven years, was noted to have a posterior lumbar slip and associated degenerative changes, but the level of slippage was not specified. Since posterior slips are mostly degenerative,[30–32] this subject was classified as having ASL as well. All together, 40 ASL cases were identified, resulting in a total of 44 non-spondylolytic spondylolisthesis lesions above L5, as revealed in the descriptive files of their radiographic reports. There were more posterior slips ($n = 24$) than anterior slips ($n = 14$), although the direction of slips was not specified in the other six lesions. The proportion of subjects complaining of low back pain in the past 12 months was 75% among those with ASL and 50% among those without ASL. Forty nine per cent of drivers with ASL sought medical attention for their back pain, but only 28% of those without ASL received medical attention for their back pain in the past 12 months.

Crude estimates of the ASL prevalence, stratified by professional seniority ($\leqslant 5$, 6–15, and >15 years), were 1.1%, 2.4%, and 7.1% respectively. When the direction of slips is considered, the prevalence of anterior ASL (2.6%; 95% CI 1.1 to 5.0) was similar to the prevalence of posterior ASL (3.3%; 95% CI 1.6 to 5.8) among those who were professionally the most senior drivers. The tendency of increasing ASL associated with professional seniority was also significant for both anterior slips (trend test $p = 0.02$) and posterior slips (trend test $p = 0.01$). Univariate analyses also indicated that biological age, overweight and obesity (BMI $\geqslant 25$ kg/m^2), and frequent strenuous exercise (more than three times/week), were all significantly ($p < 0.05$) associated with higher ASL prevalence.

The small case number prohibited us from constructing multiple logistic models for either anterior or posterior slips. Since the results of crude analyses indicated no differential effect of professional seniority on ASL prevalence between anterior and posterior slips, we pooled all ASL cases in the multiple logistic regression analyses (table 2). After adjusting for age, gender, BMI, smoking, alcohol drinking, frequency of heavy lifting, bending and twisting, and strenuous exercise, professional seniority was significantly associated with increased prevalence of spondylolisthesis (trend test $p = 0.02$). Using the prevalence in the professionally junior drivers ($\leqslant 5$ years) as the baseline, the adjusted OR was 1.9 (95% CI 0.6 to 6.1) for those with taxi driving history of 6–15 years, and 3.4 (95% CI 1.1 to 10.7) for the most senior (>15 years) drivers. In contrast to the larger crude ORs (2.2 and 6.8 respectively), such decreases of OR estimates resulted mainly from the confounding by drivers' biological age, as older drivers usually had a longer history of professional driving. The observed positive association with drivers' age, body mass index, and frequent strenuous exercise remained statistically significant in the adjusted analysis.

Neither the frequency of physical activities (lifting tasks, bending/twisting) at work, nor the psychosocial factors, such as job dissatisfaction, self-perceived stress, and mental health score, had consistent associations with the ASL prevalence in this cohort. These factors did not confound the OR estimates for professional seniority and for all other significant factors either. The result of Hosmer-Lemeshow test ($p = 0.73$) supported the goodness-of-fit of the multiple logistic model.

DISCUSSION

Our epidemiological study provides the first analytical results suggesting an association between acquired lumbar spondylolisthesis and taxi driving. Unlike previous studies on tractor drivers and helicopter pilots, the observed association between professional seniority and increase in the prevalence of spondylolisthesis remained statistically significant after adjusting for a set of potential confounders including daily driving duration, age, and physical activities.

A few physical factors associated with taxi driving can impose significant biomechanical strains on the lumbar spine. These biomechanical responses may accumulate over time and become sufficient for the development or progression of ASL. Firstly, experimental studies[33–35] have shown that the anterior shear force is one major determinant of spondylolisthesis. In their daily occupational activities, taxi drivers may be exposed to imbalanced shearing force, either transferred by shock events[36 37] when riding over bumps and jolts or resulting from collision accidents with significant translational impacts. As drivers are sitting within a confined space behind the wheel, the strong coupling between the seat backrest and vehicle floor[38] can result in a differential motion between backrest and seat pan, which may create a continuing shear force acting on the spinal segment. Secondly, researchers have found that the integrity of the disc is important to resist shear force.[34 39] An animal study[40] has shown that exposure to vibration decreases the proteoglycan content in the nucleus pulposus, and eventually results in disruption of matrix integrity. In the earlier study on helicopter pilots, investigators had suggested that

Table 1 Distribution of demographic features and occupational factors of 1242 participants in the Taxi Drivers' Health Study (TDHS)

Characteristics	TDHS participants		Drivers not in selected hospital*		Reference†
	N_1‡	Mean (SD) or %	N_2‡	Mean (SD) or %	Mean or %
Age (years)	1242	44.5 (8.7)	1403	46.6 (8.7)	43.9
Professional seniority (years)	1234	11.4 (7.8)	1890	11.0 (7.5)	9.2
Total days of driving/month (days)	1239	26.2 (2.6)	1780	25.2 (3.6)	26.8
Hours of driving/day (hours)	1238	9.8 (2.8)	1889	9.9 (2.5)	10
Body mass index (kg/m^2)	1242	24.9 (3.6)	1780	25.2 (3.6)	–
Gender					
Male	1193	96%	1854	96%	97%
Female	49	4%	82	4%	3%
Education					
Below high school	405	33%	770	40%	–
High school	782	63%	1067	56%	–
College and beyond	53	4%	69	4%	–
Marital status					
Single	201	16%	257	14%	–
Married	960	75%	1469	77%	–
Separated/divorced/widowed	116	9%	178	10%	–
Registration type					
Individual	497	40%	808	43%	–
Cooperative	395	32%	606	33%	–
Cab company affiliated	341	28%	447	24%	–
Lifting activities					
Never/rare/seldom	604	49%	–	–	–
Often/sometimes	508	41%	–	–	–
Very frequently	122	10%	–	–	–
Bending/twisting					
Never/rare/seldom	643	52%	–	–	–
Often/sometimes	482	39%	–	–	–
Very frequently	111	9%	–	–	–
Leisure time physical exertion					
Never/rare/seldom	602	49%	–	–	–
Often/sometimes	506	41%	–	–	–
Very frequently	126	10%	–	–	–
Perceived job stress					
None	282	23%	–	–	–
Mild	639	52%	–	–	–
Moderate–severe	311	25%	–	–	–
§Mental health score (0–100)	1218	63.1 (16.8)	–	–	–
¶Job dissatisfaction index (0.01–1)	1225	0.61 (0.17)	–	–	–
**Low back pain in past 12 months	628 (1241)	51%	988 (1798)	55%	–

*Drivers who received medical examinations in hospitals other than the study base hospital.
†Obtained from the Department of Statistics, Ministry of Transportation and Communication, Taiwan (34).
‡N_1, number of subjects in TDHS group; N_2, number of subject not in study base. The total number summed up across each category varies slightly due to missing data.
§Assessed by the SF-36, Chinese version.
¶Assessed by the Job Content Questionnaire, Chinese version.
**Assessed by the modified Nordic Musculoskeletal Questionnaire.

intensive vibration stress during flight might cause the observed high frequency of spondylolisthesis. However, it is noteworthy that taxi drivers, in general, are exposed to a relatively lower level of whole body vibration than other professional drivers. Whether long term exposure to low levels of whole body vibration could also disrupt the integrity of disc tissues remains unclear. Thirdly, direct back injury during motor vehicle accidents was another physical hazard associated with professional driving that could possibly cause traumatic spondylolisthesis. Interestingly, none of the 40 ASL cases reported ever having a back injury incurred during motor vehicle accidents. A likely explanation for this observation is that, because of the demanding driving tasks, taxi drivers with a history of motor vehicle related back injuries might have chosen to leave this occupation and thus were not observed in our cross-sectional study.

We are aware of no other prevalence data on acquired spondylolisthesis of professional drivers. However, we may have underestimated the overall prevalence (3.2% as a crude estimate; 95% CI 2.4 to 4.5) for a few reasons. Firstly, due to the long driving time (on average 10 hours per day, 26 days per month) demanded in the taxicab business in Taipei City, those with lumbar spondylolisthesis, whether developmental or acquired, are likely to be selected out in the course of their career. Such a selection bias may also underestimate the OR estimates. Secondly, although degenerative spondylolisthesis is four times more common in women than in men,[7] the female population is underrepresented (only 3–4%) among taxi drivers in Taipei City. Thirdly, since 15% of spondylolisthetic lesions can only been seen by a standing lateral,[41] using supine plain radiographs only would have missed a few cases of ASL not otherwise seen on a supine lateral view. Interestingly, however, Farfan[42] found that the prevalence of degenerative spondylolisthesis in a cadaver study was 4.1%. Among those taxi drivers aged above 45, with low back pain, the ASL prevalence was 8.9%, similar to the prevalence of degenerative spondylolisthesis (8.7%) reported by Iguchi and colleagues[12] who examined the radiographs of 3259 Japanese outpatients with low back disorders and comparable ages.

The observed associations between lumbar spondylolisthesis and other personal factors (age, BMI, and strenuous exercise) conform to the results of previous studies. The age dependent degenerative arthritis of the facet joints could lead

Table 2 Summarised results of crude prevalence and multiple logistic regression† for estimating the prevalence odds ratios of spondylolisthesis associated with personal and occupational factors

Factors	N (prevalence)‡	Prevalence ORs and 95% CIs: Crude OR (95% CI)	Prevalence ORs and 95% CIs: Adjusted OR (95% CI)¶
Professional seniority (years)			
⩽5	359 (1.1%)	1	1
6–15	543 (2.4%)	2.2 (0.7 to 6.7)	1.9 (0.6 to 6.1)
>15	324 (7.1%)	6.8 (2.3 to 19.8)**	3.4 (1.1 to 10.7)*
Trend test		$p<0.001$	$p=0.02$
Age (years)			
⩽45	688 (1.3%)	1	1
46–55	383 (4.7%)	3.7 (1.7 to 8.4)**	2.6 (1.1 to 6.6)*
>55	163 (8%)	6.5 (2.7 to 15.6)**	4.8 (1.8 to 12.9)**
Trend test		$P<0.001$	$p=0.002$
Gender			
Male	1185 (3.1%)	1	1
Female	49 (6.1%)	2.0 (0.6 to 6.8)	1.9 (0.5 to 7.2)
Body mass index (kg/m^2)			
<25	644 (2.1%)	1	1
⩾25	550 (4.5%)	2.2 (1.1 to 4.2)*	2.2 (1.1 to 4.6)*
Frequent strenuous exercise			
No	939 (2.6%)	1	1
Yes	293 (5.5%)	2.2 (1.2 to 4.2)*	2.2 (1.1 to 4.5)*

*$p<0.05$; **$p<0.01$.
†The Hosmer-Lemeshow test for the goodness-of-fit of the final adjusted model: $p=0.73$
‡Number of subjects and crude prevalence of spondylolisthesis in each category. The total number of subjects slightly differed across categories because of missing data. A total of 1166 subjects were included in the final logistic model.
¶Adjusted for frequency of lifting tasks, bending and twisting, smoking habit, alcohol dinking, and all the other factors indicated in the table.

to vertebral subluxation.[41] Although the lumbar facet joints[43] carry 3–35% of the static compression force on the lumbar motion segment and dynamically up to 33% of the axial load, biomechanically both the compression force and axial load are increased as the body mass increases.[35] Many studies have also described the high prevalence of spondylolisthsis among those engaged in competitive sports,[9 44 45] largely due to trauma. Although we found that spondylolisthesis was more common in female than in male taxi drivers (6.1% *v* 3.1%), the extreme under-representation of female gender in this occupation and the small number of identified lumbar spondylolisthesis (three cases only) in female drivers provided no statistical power to detect any significant gender effect reported in previous studies.

The following sensitivity analyses were carried out to examine further the robustness of the exposure-response relation between professional seniority and prevalence of lumbar spondylolisthesis. Firstly, to examine whether our findings were sensitive to the restricted definition of ASL, we included all cases of spondylolisthesis (lytic and non-lytic) regardless of their levels of involvement, assuming that some physical exposures in this occupational setting might also contribute to the progression of isthmic spondylolisthesis. After adjusting for the same set of variables in table 2, the tendency of increasing frequency of spondylolisthesis associated with professional seniority remained statistically significant ($p = 0.04$), and more spondylolisthetic lesions were found in professionally senior drivers than in drivers with least seniority (OR = 3.0; 95% CI 1.1 to 8.6). Secondly, concerning the likelihood of residual confounding by drivers' biological ages, we took alternative approaches to adjust for the age effect. After we specified the age effect as a linear function only for age >45, professionally senior drivers still had a higher ASL prevalence than junior drivers (OR = 3.0; 95% CI 1.0 to 9.7) and the trend test remained statistically significant ($p = 0.04$). Finally, even after we restricted the analysis to drivers aged less than 55 (n = 995), we consistently observed the incremental change in ASL prevalence associated with professional seniority ($p = 0.03$), and the ASL lesions were still more frequent in professionally senior drivers than junior drivers (adjusted OR = 5.5; 95% CI 1.1 to 26.6).

Although plain radiographs have been recognised as a poor method for assessing back pain,[46 47] the popular view on the importance and usefulness of plain radiography among patients with back pain remains a substantial barrier to appropriate use of radiography.[48] One previous study in the USA found that 87% of patients believed that everyone with back pain should have plain radiograph.[49] A recent report also indicated that 72% of patients with back pain referred from Norwegian general practitioners rated radiography as very important.[50] The TDHS research committee was not directly involved in overseeing the medical examinations first established for taxi drivers in Taipei City. However, we noted that the inclusion of L-spine plain radiography also reflected the self-perceived high risk for back disorders among taxi drivers and the pervasive view on the use of L-spine plain radiography among the involved parties (medical examination providers, drivers' representatives, and the programme sponsor). Although we observed a likely association between professional seniority and prevalence of spondylolisthesis among taxi drivers, our findings should not be used to support the unconditional use of spine plain radiography in either clinical or occupational settings.

We recognise several limitations to our cross-sectional study. Firstly, without radiographic data from before the subjects began driving professionally, the association between driving seniority and spondylolisthesis cannot be definitely interpreted as causal. In fact, it has been shown that progression of slippage occurs in 30% of patients with degenerative spondylolisthesis.[51] The observed cross-sectional association may suggest that some physical exposures related to professional driving are prognostic factors accelerating progression of existing lumbar spondylolisthesis, but not aetiological factors causing lumbar spondylolisthesis. Secondly, although the AP and lateral L-spine radiograph taken with recumbent positioning is commonly applied to many clinical settings to examine lumbar spine abnormalities, it is a sub-optimal tool for the radiological diagnosis of spondylolisthesis. Without the more sensitive standing lateral views or additional knowledge from the oblique views of L-spines, a few spondylolytic lesions may have been missed, resulting in misclassification of some identified ASL cases. Similarly, restricting the ASL cases to those involved lumbar spines above L5 may not capture those degenerative or traumatic lesions over lumbosacral spines. Despite the possibility of outcome misclassification, it is unlikely that the consistently significant association in both crude and adjusted analyses is spurious since the examination and interpretation of L-spine was done blind to professional seniority, and any resulting non-differential misclassification would more likely have biased the association towards the null.

Conclusion

Our cross-sectional study showed a consistent and robust exposure-response relation between professional seniority and prevalence of acquired lumbar spondylolisthesis among taxi drivers. Prospective epidemiological studies are needed to confirm the postulated association between professional driving and spondylolisthesis and further examine the specific occupational exposures accountable for this association.

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REFERENCES

1 **Neugebauer FL**. The classic: a new contribution to the history and etiology of spondylolisthesis. *Clin Orthop* 1976;(117):4–22.
2 **Moller H**, Sundin A, Hedlund R. Symptoms, signs, and functional disability in adult spondylolisthesis. *Spine* 2000;**25**:683–90.
3 **Marty C**, Boisaubert B, Descamps H, *et al*. The sagittal anatomy of the sacrum among young adults, infants, and spondylolisthesis patients. *Eur Spine J* 2002;**11**:119–25.
4 **Taillard WF**. Etiology of spondylolisthesis. *Clin Orthop* 1976;(117):30–9.
5 **Fredrickson BE**, Baker D, McHolick WJ, *et al*. The natural history of spondylolysis and spondylolisthesis. *J Bone Joint Surg* 1984;**66**:699–707.
6 **Ryan MD**. L4–5 degenerative spondylolisthesis in monozygous twins. *Spine* 1994;**19**:985–6.
7 **Rosenberg NJ**. Degenerative spondylolisthesis. Predisposing factors. *J Bone Joint Surg* 1975;**57**:467–74.
8 **Tower SS**, Pratt WB. Spondylolysis and associated spondylolisthesis in Eskimo and Athabascan populations. *Clin Orthop* 1990;(250):171–5.
9 **Jakab G**. Occupational spondylolysis and spondylolisthesis. *Baillieres Clin Rheumatol* 1989;**3**:89–98.
10 **Dai LY**. Orientation and tropism of lumbar facet joints in degenerative spondylolisthesis. *Int Orthop* 2001;**25**:40–2.
11 **Grobler LJ**, Robertson PA, Novotny JE, *et al*. Etiology of spondylolisthesis. Assessment of the role played by lumbar facet joint morphology. *Spine* 1993;**18**:80–91.
12 **Iguchi T**, Wakami T, Kurihara A, *et al*. Lumbar multilevel degenerative spondylolisthesis: radiological evaluation and factors related to anterolisthesis and retrolisthesis. *J Spinal Disord* 2002;**15**:93–9.
13 **Nagaosa Y**, Kikuchi S, Hasue M, *et al*. Pathoanatomic mechanisms of degenerative spondylolisthesis. A radiographic study. *Spine* 1998;**23**:1447–51.
14 **Christ W**, Dupuis H. Untersuchubg der Möglichkeit von gesundlichen Schädigungen im Bereich der Wirbelsäule bei Schlepperfahrern. *Med Welt* 1968;**36**:1919–20, 67–72.
15 **Hulshof C**, van Zanten BV. Whole-body vibration and low-back pain. A review of epidemiologic studies. *Int Arch Occup Environ Health* 1987;**59**:205–20.
16 **Fisher V**, Witt AN, Tröger O, *et al*. Vribrationbedinte Wirbelsäuleschäden bei Hubschrauberpiloten. *Arbeitsmed Sozialmed Präventivmed* 1980;**15**:161–3.
17 **Froom P**, Froom J, Van Dyk D, *et al*. Lytic spondylolisthesis in helicopter pilots. *Aviat Space Environ Med* 1984;**55**:556–7.
18 **IOSH**. *Occupational safety evaluation of taxi drivers in Taipei City*. Taipei City: Taiwan Institute of Occupational Safety and Health (IOSH), Council of Labor Affairs, 2000.
19 **Chen JC**, Chang WR, Shih TS, *et al*. Predictors of whole-body vibration among urban taxi drivers. *Ergonomics* 2003;**46**:1075–90.
20 **Marchetti PG**, Bartolozzi P. Classification of spondylolisthesis as a guideline for treatment. In: Bridwell KH, Dewald RL, eds. *The textbook of spinal surgery*, 2nd edn. Philadelphia, PA: Lippincott-Raven, 1997:1211–54.
21 **Osterman K**, Schlenzka D, Poussa M, *et al*. Isthmic spondylolisthesis in symptomatic and asymptomatic subjects, epidemiology, and natural history with special reference to disk abnormality and mode of treatment. *Clin Orthop* 1993;(297):65–70.
22 **Vaccaro AR**, Martyak GG, Madigan L. Adult isthmic spondylolisthesis. *Orthopedics* 2001;**24**:1172–79.
23 **Meyerding HW**. Low backache and sciatic pain associated with spondylolisthesis and protruded intervertibral disc. *J Bone Joint Surg (Am)* 1941;**23**:461.
24 **Baron S**, Hales T, Hurrell J. Evaluation of symptom surveys for occupational musculoskeletal disorders. *Am J Ind Med* 1996;**29**:609–17.
25 **Kuorinka I**, Jonsson B, Kilbom A, *et al*. Standardized Nordic Questionnaires for the analysis of musculoskeletal symptoms. *Appl Ergon* 1987;**18**:233–7.
26 **Cheng Y**, Luh WM, Guo YL. Reliability and validity of the Chinese version of the Job Content Questionnaire in Taiwanese workers. *Int J Behav Med* 2003;**10**:15–30.
27 **Fuh JL**, Wang SJ, Lu SR, *et al*. Psychometric evaluation of a Chinese (Taiwanese) version of the SF-36 health survey amongst middle-aged women from a rural community. *Qual Life Res* 2000;**9**:675–83.
28 **Lemeshow S**, Hosmer DW Jr. A review of goodness of fit statistics for use in the development of logistic regression models. *Am J Epidemiol* 1982;**115**:92–106.
29 **MOTC**. *Survey report on taxi service business*. Taipei City: Taiwan Ministry of Transportation and Communications, 2000.
30 **Canale ST**, Campbell WC. *Campbell's operative orthopaedics*, 10th edn. St Louis: Mosby, 2003.
31 **Kauppila LI**, Eustace S, Kiel DP, *et al*. Degenerative displacement of lumbar vertebrae. A 25-year follow-up study in Framingham. *Spine* 1998;**23**:1868–74.
32 **Nizard RS**, Wybier M, Laredo JD. Radiologic assessment of lumbar intervertebral instability and degenerative spondylolisthesis. *Radiol Clin North Am* 2001;**39**:55–71, v–vi.
33 **Konz RJ**, Goel VK, Grobler LJ, *et al*. The pathomechanism of spondylolytic spondylolisthesis in immature primate lumbar spines in vitro and finite element assessments. *Spine* 2001;**26**:E38–49.
34 **Troup JD**. Mechanical factors in spondylolisthesis and spondylolysis. *Clin Orthop* 1976;(117):59–67.
35 **Farfan HF**, Osteria V, Lamy C. The mechanical etiology of spondylolysis and spondylolisthesis. *Clin Orthop Related Res* 1976;(117):40–55.
36 **Wilder DG**. The biomechanics of vibration and low back pain. *Am J Ind Med* 1993;**23**:577–88.
37 **Pope MH**, Kaigle AM, Magnusson M, *et al*. Intervertebral motion during vibration. Proceedings of the Institution of Mechanical Engineers. Part H. *J Eng Med* 1991;**205**:39–44.
38 **Johnson DA**, Neve M. Analysis of possible lower lumbar strains caused by the structural properties of automobile seats: a review of some recent technical literature. *J Manipulative Physiol Ther* 2001;**24**:582–8.
39 **Crawford NR**, Cagli S, Sonntag VK, *et al*. Biomechanics of grade I degenerative lumbar spondylolisthesis. Part 1: in vitro model. *J Neurosurg* 2001;**94**:45–50.
40 **Ishihara H**, Tsuji H, Hirano N, *et al*. Effects of continuous quantitative vibration on rheologic and biological behaviors of the intervertebral disc. *Spine* 1992;**17**:S7–12.
41 **Herkowitz HN**. Spine update. Degenerative lumbar spondylolisthesis. *Spine* 1995;**20**:1084–90.
42 **Farfan HF**. The pathological anatomy of degenerative spondylolisthesis. A cadaver study. *Spine* 1980;**5**:412–18.
43 **Yang KH**, King AI. Mechanism of facet load transmission as a hypothesis for low-back pain. *Spine* 1984;**9**:557–65.
44 **Muschik M**, Hahnel H, Robinson PN, *et al*. Competitive sports and the progression of spondylolisthesis. *J Pediatr Orthop* 1996;**16**:364–9.
45 **Rossi F**. Spondylolysis, spondylolisthesis and sports. *J Sports Med Phys Fitness* 1978;**18**:317–40.

46 **Agency for Health Care Policy and Research**. *Acute low back problems in adults: assessment and treatment.* Rockville, MD: US Dept of Health and Human Services Public Health Service, 1994.
47 **Royal College of Radiologists**. *Making the best use of a department of clinical radiology: guidelines for doctors*, 3rd edn. London: Royal College of Radiologists, 1995.
48 **Roland M**, van Tulder M. Should radiologists change the way they report plain radiography of the spine? *Lancet* 1998;**352**:229–30.
49 **Deyo RA**, Diehl AK, Rosenthal M. Reducing roentgenography use. Can patient expectations be altered? *Arch Intern Med* 1987;**147**:141–5.
50 **Espeland A**, Baerheim A, Albrektsen G, *et al*. Patients' views on importance and usefulness of plain radiography for low back pain. *Spine* 2001;**26**:1356–63.
51 **Matsunaga S**, Sakou T, Morizono Y, *et al*. Natural history of degenerative spondylolisthesis. Pathogenesis and natural course of the slippage. *Spine* 1990;**15**:1204–10.