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Lumbar Spinal Pathology in Cadaveric Material in Relation to History of Back Pain, Occupation, and Physical Loading

TAPIO VIDEMAN, MD, DMSc,*† MARKKU NURMINEN, DrPH, PhD,* and J. D. G. TROUP, PhD, DSc(Med), M(FOM)RCP*

The occurrence of symmetric disc degeneration, anular ruptures, end-plate defects, vertebral body osteophytosis, and facet joint osteoarthrosis was examined radiographically and osteologically in 86 male cadavers for whom occupational, physical loading, and back pain histories were obtained from the men's families. History of back pain and the parameters of spinal pathology were related to the highest and lowest degrees of physical loading. In multivariate analyses, history of back injury was related to the occurrence of symmetric disc degeneration, anular ruptures, and vertebral osteophytosis. Symmetric disc degeneration was associated with sedentary work, and vertebral osteophytosis was related to heavy work. History of back pain was related to occupational physical loading after control for the effects of the other covariates. The results indicate that the least pathology stemmed from moderate or mixed physical loading, but the least back pain was associated with sedentary work. [Key words: anular ruptures, autopsy material, back pain, chemical exposure, disc degeneration, endplate defects, epidemiology, facet joint osteoarthrosis, occupation, osteophytes, physical work load, sciatica]

WHEREAS SINGLE OVERLOAD is an obvious source of immediate injury, the likelihood of injury increases with time for repeated loading that may be mechanically fatiguing and creep effects that can be induced by frequent dynamic loading and exposure to prolonged static load. Moreover, repeated microtrauma may lead accumulatively to degeneration.[3] In contrast, the onset of degeneration may be accelerated by disuse or immobilization.[48,51] Where, then, lies the interval in which the unnecessary risk from both excessive loads and the disuse that threatens the mechanical integrity of the musculoskeletal system is removed?

The phenomenon of the J-shape (or U-shape) is one that is well recognized in biology, eg, in relation to the health risks related to food intake, environmental temperature, or alcohol consumption.[47] The J-shape is also evident for spontaneous abortion risk in relation to age.[15] It is of manifest importance to the strength of the vertebral column, eg, in terms of the temporal factors of compressive failure.[47] At one extreme, the probability of injury is related to jerk or the rate of accelerative increase, while at the other, resistance to injury is inversely related to the duration of the applied load.

This much information is evident from bioengineering studies. What remains uncertain is the optimal range of exposure to physical loading at work and the extent of physiologic adaptation. Ergonomics, traditionally, has served to reduce physical work load, but how far should such reductions reasonably go? This question is especially relevant for those in the working population who are susceptible to back pain.[32,44]

Epidemiologic evidence indicates that sitting[24,25]; driving[14,20]; postural stress[22,36,38,56]; exposure to shock and vibration[10,47]; and heavy lifting and unaccustomed or unexpected loading[5,9,23,25,39,41,45,46,53–55] are occupational risk factors of back pain.

The relation between occupational exposures and lumbar spinal degeneration is not as established.[1] In some studies, disc degeneration or lumbar spondylosis was more common in men who did heavy manual work.[17–19,22,39,43] However, no such clear relation was found by Magora and Schwartz.[26] Caplan et al,[4] who x-rayed 178 miners, distinguished between disc narrowing, which was related to injury, and osteophytosis, which was age- and occupation-related. Thus, the picture is far from clear, particularly when the partial independence of degenerative changes, as diagnosed radiologically, and back symptoms at work are under consideration.[40]

The difficulty in interpreting the evidence for risk factors related to back pain at work has, in general, been the absence of firm diagnoses supported by objective pathologic criteria. It was therefore decided to study the pathology of the lumbar spine in some depth in cadaveric material. The hypothesis to be tested was that minimal pathologic changes would be found in those cadavers whose previous exposure to physical loading fell between the extremes of overexertion and inactivity. The other objective was to relate back pain histories to spinal pathology and physical loading.

MATERIALS AND METHODS

The material consisted of cadavers of men who had died in the wards or clinics of the University Hospital, Helsinki, and who then were examined in the Central Laboratory of Pathology. In a routine autopsy, the lumbar spine from L1 to S1 was examined in 149 cadavers. To be included in the study the deceased person had to be a man, below the age of 64 years, who had been employed before death and whose history of illness or disease was short. Inclusion in the study also depended on the subject's family providing information on him. This information was received in 86 cases (Table 1). Exclusion criteria were chronic illness or hospitalization and death of cancer or infectious disease. The project was approved by the Ethical Committee of the Institute of Occupational Health, Helsinki.

Cadaveric Specimens ***Discography.*** Barium sulphate ($BaSO_4$) was used as the contrast medium. A 20-gauge standard needle was inserted from the front into the center of the disc with digital pressure for

From the *Department of Epidemiology and Biostatistics, Institute of Occupational Health, Helsinki, Finland, and the †University of Jyväskylä, Jyväskylä, Finland.

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Table 1. Possibility of Chemical Exposure and the Age Distribution of 86 Subjects in Different Occupational Groups

		Chemical exposure			*Age (yrs)*	
		Unlikely	*Possible*	*Likely*		
Occupational group	*Total no.*	*(n)*	*(n)*	*(n)*	*Mean*	*SD*
Sedentary	22	21	1	0	53.0	7.3
Mixed	21	4	12	5	51.5	12.3
Driving	14	1	11	2	51.7	7,7
Heavy	29	0	22	7	53.2	6.9

which no measurements were made. The end point of the injection was either resistance to injection or, in the case of leakage through the disc, when no more than 5 ml of the mixture had been injected or when the leak became visible. Three components of disc pathology were assessed, as in the report by Videman et al.[53] First, symmetric disc degeneration was characterized by symmetric and diffuse changes, as follows (Figure 1A): 0: none; I: slight (spread of the dye into the inner anulus); II: moderate (spread of the dye from the inner to the middle region of the annulus); and III: severe (spread to the outer part of the anulus). Second, anular ruptures were characterized by the local or linear spread of the dye through the anulus fibrosus as follows (Figure 1B): 0: none; I: spread as far as the middle of the anulus; II: spread to the outer contour of the anulus; III: leakage outside the contour of the anulus; IV: anular ruptures at no less than two levels, classified as at least Grade II or III. Third, end-plate defects were characterized by the spread of the dye through the cartilaginous end-plate as follows (Figure 1C): 0: none; I: dye penetrating the cartilage but no further; II: dye through the end-plate and entering the subchondral bone but spreading not more than 3 mm by direct measurement; and III: as in II but the dye spreading more than 3 mm.

Radiography. Specimens were x-rayed and a radiologic assessment of the osteophytosis of the vertebral body was made subjectively by an experienced observer, using the following classification: 0: none; I: slight (small osteophytes restricted to one adjacent intervertebral segment); II: moderate (substantial osteophytes in more than one direction); and III: severe (general osteophytosis).

Osteology. Lumbar vertebrae were prepared by boiling, removal of fat, and bleaching according to using the method described by Malmi-

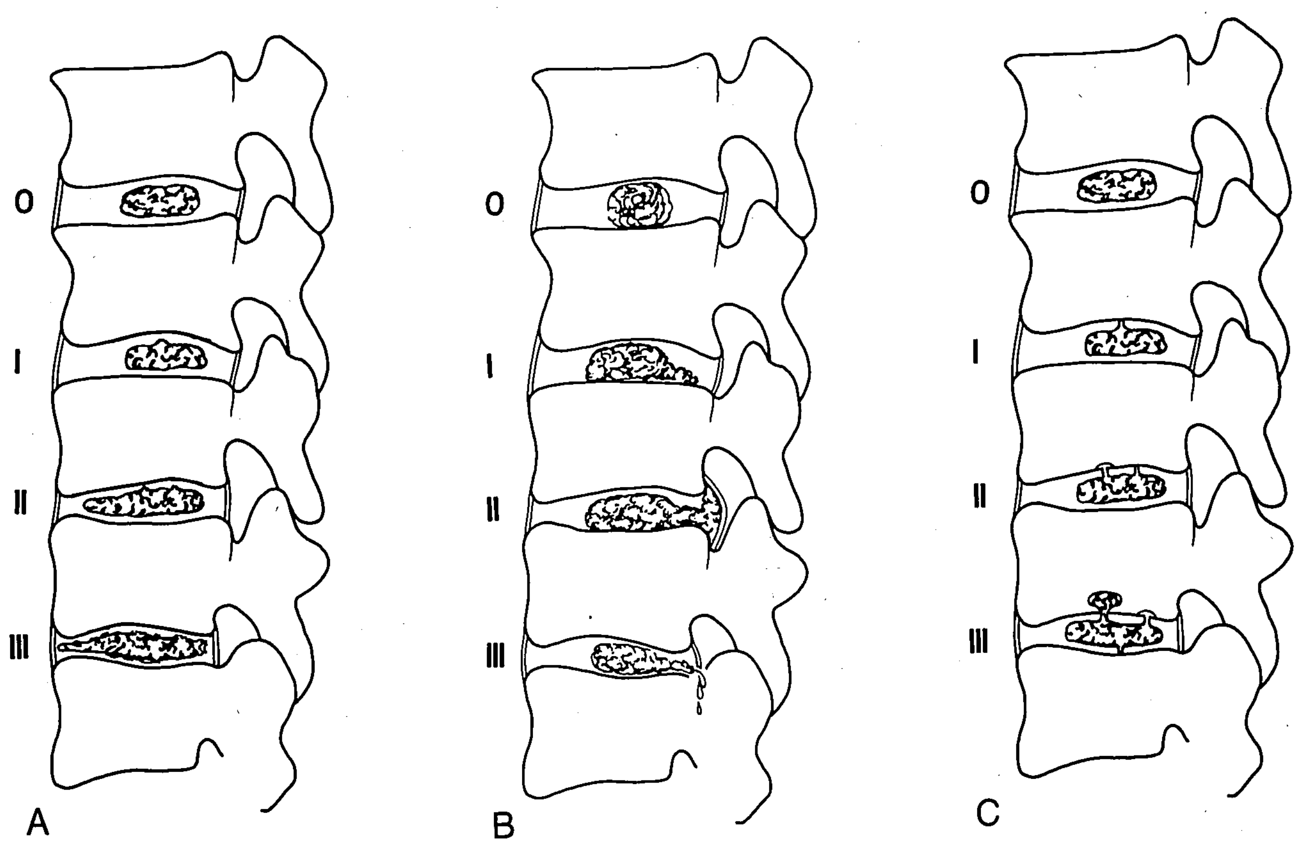

Fig 1. A, Classification of symmetric disc degeneration: 0 = none; I = slight; II = moderate; and III = severe. **B,** Classification of anular ruptures: 0 = none; I = slight, where the contrast medium extends through the anulus but is inside the contour of the normal disc; II = moderate, where the contrast medium goes through the anulus but is not outside of the contour of the disc; and III = severe, where the dye leaks outside the contour of the anulus. **C,** Classification of end-plate defects: 0 = none; I = dye penetrating only the cartilage; II = dye seen also in subchondral bone but, spreading not more than 3 mm in diameter; and III = as in II, but the dye spreading more than 3 mm.*

vaara et al.[27] The degree of facet osteoarthrosis then was assessed subjectively (Figure 2) and classified as follows: 0: none; I: slight; II: moderate; and III: severe.

Reliability for the Parameters of Spinal Pathology. For the measurement of intraobserver reliability, random samples were evaluated twice. The weighted kappa measure of agreement[8] was 0.81 for symmetric disc degeneration, 0.80 for anular ruptures and 0.92 for end-plate defects for discograms of L4–5. The agreement of the osteophyte assessments made from the plain roentgenograms was 0.30 (L4) when compared with the assessments made of the bony specimens. The reliability of the evaluation of facet joint degeneration was based on two assessments of the osteologic data, and the kappa agreement measure was 0.57.

Occupational Groups. The occupational history of the subjects was obtained initially from the information recorded on the death certificate and from information given by members of the family (cf. Koskela et al).[21] A questionnaire was first posted to the family. It was followed, when necessary, by a telephone interview. When an individual had had more than one job, the physically heaviest occupation held for at least 5 years was used as the definitive occupation. The occupations then were classified as sedentary, mixed (degree of heaviness), driving, and heavy by two experienced occupational health physicians independently and then, when necessary, by agreement (Table 1).

The occupations were further rated by the two physicians according to chemical exposure, eg, solvents, toxic products, and noxious gases. The exposure then was classified as unlikely, possible, or likely (Table 1).

History of Back Pain, Injury, Disability, and Physical Loading. The family was asked about the subject's history of back pain, back injury, disability due to back pain, and physical loading of the back. The first question was: "Did he have back pain? If so, how often?" The replies were as follows: "No back pain" (n = 32); "Sometimes—less than once a year" (n = 22); "Often—at least once a year" (n = 30). For those with back pain, the family was asked about the type of pain, the replies being classified as sciatic, ie, back pain radiating to the limbs (n = 21) or other back pain (n = 31). For any subject who had had back pain sometimes or often, information was requested on whether he had been unable to work for at least 1 month because of back pain or injury. The replies were either: "Yes" (n = 8) or "No" (n = 42). Each subject's family was also asked if he did heavy physical work before the age of 20 years and, if so, for how long? The replies were: "No" (n = 18); "Yes—less than 3 years" (n = 17); "Yes—3 years or more" (n = 34); "Not known" (n = 17). Thereafter a question on whether, after the age of 20 years, the subject exercised either as a hobby or to keep physically fit and, if so, for how long he had done so? The replies were: "No or less than 1 year" (n = 38); "Yes—for 1–15 years" (n = 17); "Yes—for more than 15 years" (n = 26).

Statistical Methods. The statistical analysis of the epidemiologic (radiographic, osteologic, and questionnaire) data aimed at quantifying (i) the relation of back pain to occupation and pathophysiologic changes in the spine, (ii) the association of spinal morphology to physical loading and occupational factors, and (iii) the interrelation of these conditions.

To analyze the effect of physical work load on disease of the lumbar spine, we used cross-classification and modeling approaches. To begin with the association between the heaviness of the subject's physical work and degeneration of the intervertebral disk, facet joint, etc., was examined in bivariate contingency tables. The degree of degeneration was taken as the outcome variable and the type of work as the determinant variable. The levels of intervertebral disc were used to define the strata. In separate analyses, sedentary work, driving work, and heavy work were contrasted with mixed work. The outcome variables were treated as ordinally scaled, score values 0, 1, 2, 3, etc., being assigned to the categories of increasing severity of disease. The hypothesis of a progressive dependence (or trend) between work and degeneration was tested by the correlation statistic, which follows a chi-square distribution on 1 degree of freedom (*df*) separately for each stratum.[29] (The computation of trend statistics across strata was not valid because the observations for an individual spine are not independent.)[28]

On the assumption that the most advanced form of disc degeneration was the most relevant finding, the cases (ie, those with the highest overall grade (III) for disease state) were compared with the noncases (ie, those with a highest overall grade of less than III) in terms of the case-referent exposure-odds ratio. However, the odds ratio obtained under the ("cumulative") sampling design does not consistently estimate any biologically meaningful parameter unless the proportion exposed (to chemicals etc.) is constant over the study period.[12] In particular, the upward bias in using the odds ratio to estimate risk ratio (ie, ratio of two cumulative incidence rates or incidence proportions) can be considerable when the cumulative incidence rates are, say, greater than 50% in either subgroup. It is thus necessary to consider the constancy of the exposure proportion when results from the case-referent analysis are being interpreted.

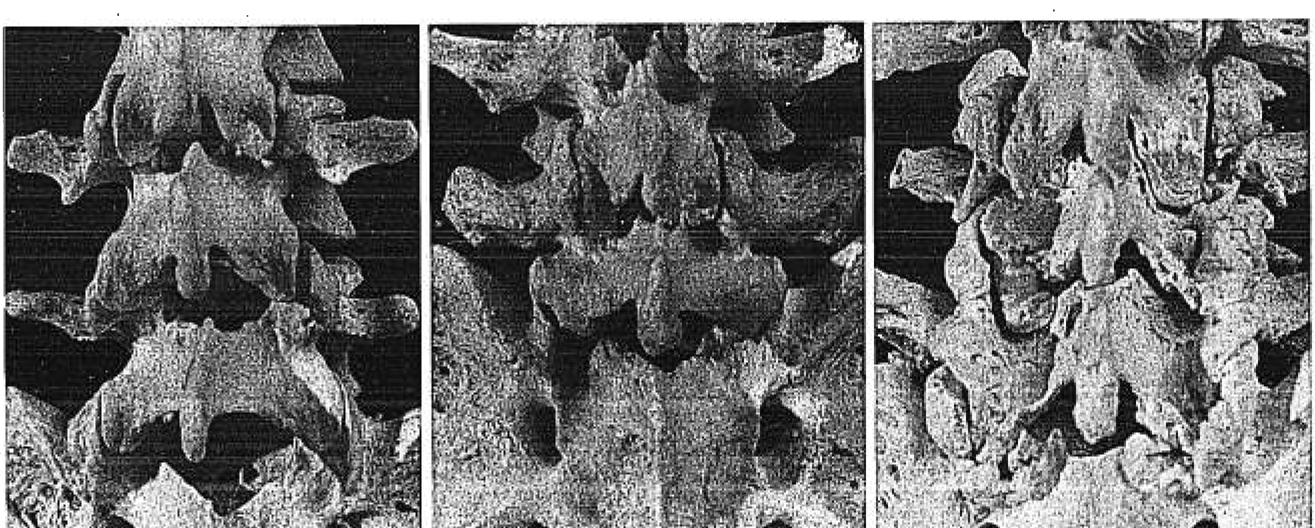

Fig 2. Examples of the classification of apophyseal intervertebral joint osteoarthrosis: the spine on the left was classified as 0, in the middle as I, and that on right as III.

To include covariate information (on age, physical exercise, disabling accidents, etc.) in the analysis multiple logistic regression modeling[2] was applied for the probability of having a severe pathologic finding. The goodness of fit of the models was tested by the likelihood ratio chi-square statistic.

In addition, an average grade for disease state was computed that was approximately normally distributed. Analysis of covariance models then were fitted using the method of least squares to the normal scores with contrasts between the different levels of the covariates tested by the F-statistic based on partial sums of squares.

Recognizing that a history of pain is not a disease entity and thus it is ineligible as an outcome variable in a model for disease occurrence, we first studied the association of a history of pain with spinal pathology in contingency tables. Finally, the interrelations of the variables, particularly with a history of back pain, were examined via loglinear models.[2]

The appropriate procedures in the SAS/STAT (SAS Institute Inc, Cary, NC) program system[42] were used for the statistical computations.

RESULTS

Back Pain, Occupation, and Spinal Pathology

For the history of back pain, sciatica, and disability from back pain or injury for at least 1 month, the incidence proportions were greatest for heavy occupation and driving. For back pain experience and sciatica, the bar graphs displayed a J-shaped relation with heaviness of work, whereas a linear relation was evident for disability (Figure 3).

With regard to the parameters of spinal pathology, anular ruptures depicted the clearest differences in the incidence proportion of back pain (Figure 4) and sciatica. Disabling back pain and sciatica were less frequent with severe end-plate defects, however—unlike back pain itself.

Progression of Spinal Pathology and Heaviness of Work

The frequency of the pathologic findings in the lumbar spine can be found in the Appendix separately for symmetric disc degeneration, anular ruptures, end-plate defects, osteophytosis of the vertebral body, and facet joint osteoarthrosis. A test of the progressive dependence between type of work and degree of pathologic changes indicated that the significant changes tended to be located in the lower level of the vertebra rather than in the upper level (Tables A1–A5). For heavy work, the pathologic progression was faster than for mixed work for each outcome variate except anular ruptures. Conversely, for driving the progression was slower than for mixed work with respect to disc degeneration, anular ruptures, and end-plates at the intervertebral level of L23.

Symmetric Disc Degeneration. Sedentary and heavy work seemed to be more clearly related to a severe level of symmetric disc degeneration (Grade III) than mixed and driving work. However, for exercising, either >15 years or <1 year after the age of 20 years was more strongly related to this variable than exercising for 1–15 years. Another risk factor for symmetric disc degeneration was injury. In addition, the incidence proportion of degeneration rose ostensibly with the likelihood of chemical exposure (Figure 5).

The odds ratios from the multivariate (logistic regression) analysis are shown in Table 2. The statistically significant factors for severe symmetric disc degeneration were aging ($P = 0.002$), sedentary work ($P = 0.026$) and history of back injury ($P = 0.030$).

Anular Ruptures. Aging, physical exercise, and heaviness of occupation seemed to have no effect on the incidence proportions for severe anular ruptures (Grades III and IV). The most frequent occurrence was seen in subjects in the driving profession (Figure 6). The only statistically significant regressor from the logistic analysis was history of back injury ($P < 0.05$) (Table 2).

End-Plate Defects. Although heavy work was more closely related to moderate and severe end-plate defects (Grades II and III) than the other types of work were and although >15 years of exercising and <1 year or no exercise after the age of 20 years was more closely related than 1–15 years of exercise, the only significant factor from the multivariate analysis was aging ($P = 0.01$) (Table 2). Nevertheless, a J-shaped bar diagram was discernible according to the heaviness of work and years of exercise (Figure 7).

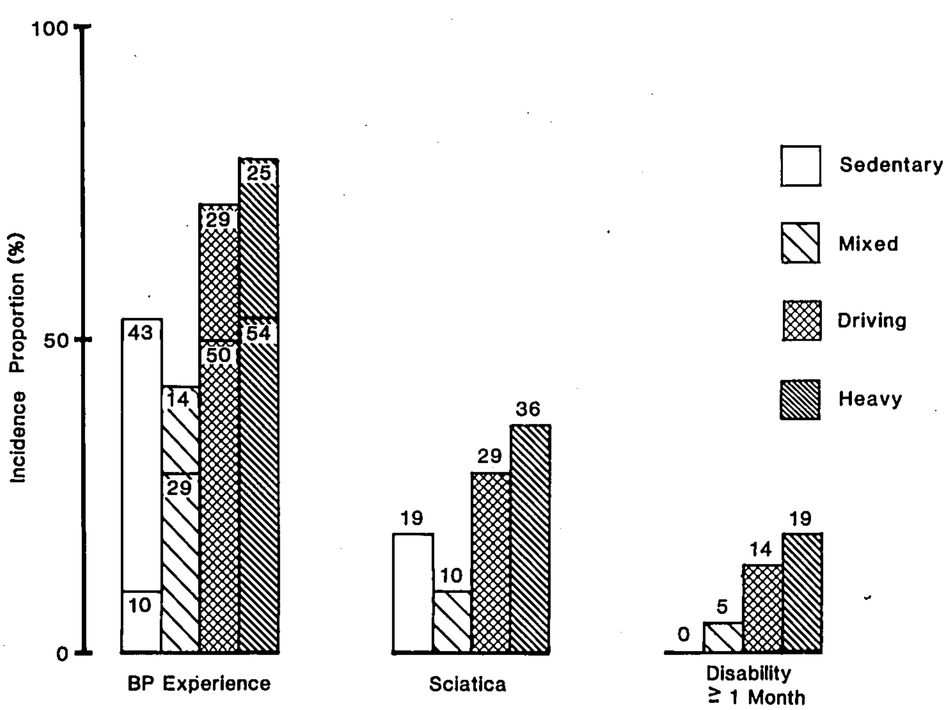

Fig 3. Incidence proportion of back pain (BP) experience in the four occupational groups. The lower part of each column represents the answer "often" and the upper "sometimes". The P-value for occupational differences was 0.01 for back pain experience, <0.07 for sciatica, and <0.05 for disability.

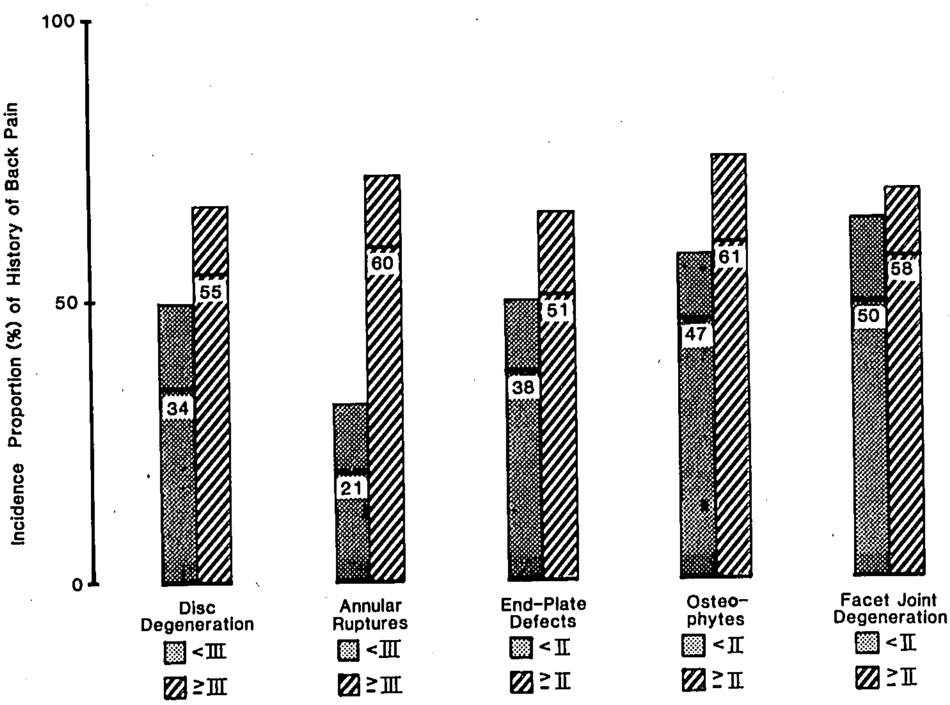

Fig 4. Occurrence of a history of back pain in relation to the degree of different pathologic findings. The only statistically significant difference in incidence proportions was in relation to anular ruptures ($P = 0.05$).

Osteophytosis of the Vertebral Body. Heavy work appeared to be related to moderate and severe osteophytosis of the vertebral body (Grades II and III) more clearly than driving (Figure 8). The significant variates from the multivariate analysis were history of back injury ($P = 0.005$), aging ($P = 0.01$), and heavy work ($P = 0.025$) (Table 2).

Facet Joint Osteoarthrosis. The J-shape relation for the incidence proportions of moderate and severe facet joint osteoarthrosis (Grades II and III) was evident in the amount of heavy physical work before 20 years of age, those with less than 3 years being the least at risk for facet osteoarthrosis. Likewise, with physical exercise after 20 years of age, those who had exercised for 1–15 years were the least at risk of facet osteoarthrosis (Figure 9). However, the multivariate analysis indicated that the only significant factor was aging ($P = 0.007$) (Table 2).

In the preceding analyses, the most advanced state of disc degeneration was taken as the outcome variate. An alternative is to consider the average degree of degeneration across the vertebral levels. This pathology score is shown in Table 3 for symmetric disc degeneration to be significantly higher in the class with <1 year of physical exercise than in the class with >1 years of exercise. Subjects in mixed occupations had a lower mean score of end-plate defects than those in other

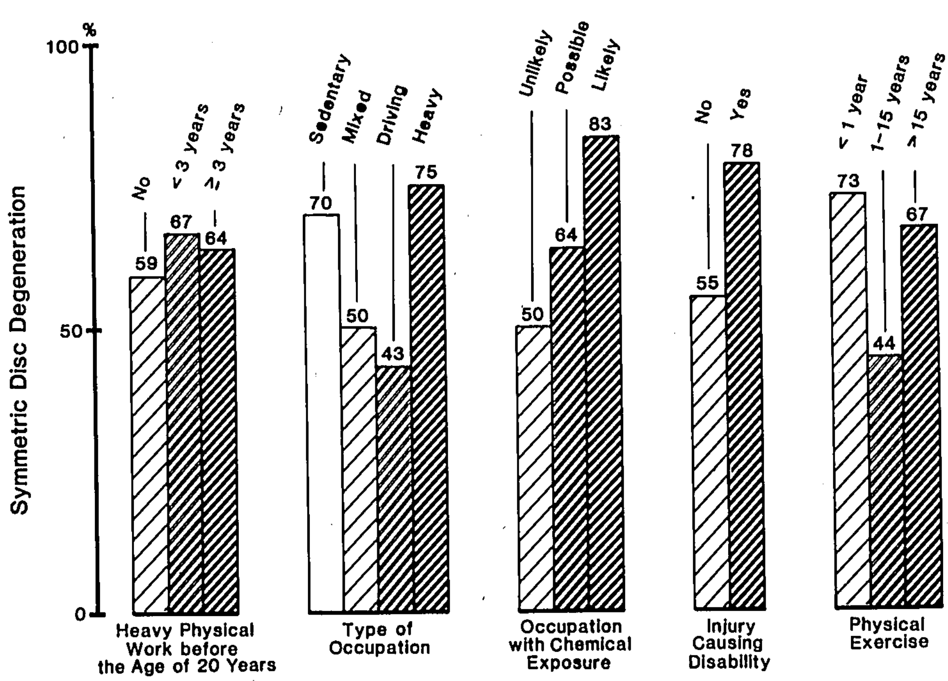

Fig 5. Occurrence of symmetric disc degeneration (Grade III) in different categories of five occupational and physical loading determinants.

Table 2. Odds Ratios (OR) and Their 95% Confidence Intervals (95% CI) from the Multivariate Logistic Analysis for Physical Loading, Occupational Factors, and Age in Relation to Pathologic Outcomes for the Spine

		Symmetric disc degeneration		*Anular ruptures*		*End-plate defects*		*Vertebral osteophytosis*		*Facet joint osteoarthrosis*	
Model variate	*Classification*	*OR*	*95% CI*	*OR*	*95% CI*	*OR*	*95% CI*	*OR*	*95% CI*	*OR*	*95% CI*
Heavy work before 20 years of age (Reference=No)	< 3 years	1.8	0.2-15.6	0.6	0.1-3.3	1.1	0.2-7.3	2.0	0.3-16.1	0.4	0.1-2.7
	≥ 3 years	2.6	0.2-26.4	2.5	0.3-20.8	2.6	0.4-19.2	1.1	0.1-10.2	2.2	0.3-15.0
	Missing	3.2	0.3-36.1	1.4	0.2-10.6	2.1	0.2-17.8	16.1	1.0-251	1.8	0.2-16.0
Type of work (Reference=Mixed)	Sedentary	24.6	1.5-409	1.0	0.2-6.1	4.0	0.5-29.8	1.1	0.6-81.7	8.1	0.7-90.6
	Driving	1.9	0.2-20.3	2.9	0.4-21.7	2.3	0.3-18.4	0.5	0.03-8.3	1.4	0.1-14.5
	Heavy	2.8	0.3-23.7	0.7	0.1-4.6	5.0	0.6-35.4	12.1	1.4-107	3.1	0.4-22.0
Chemical exposures (Reference=Unlikely)	Possible—likely	3.1	0.6-16.0	1.7	0.4-7.9	3.4	0.5-21.6	0.7	0.1-3.6	1.8	0.4-9.2
Injury with disability (Reference=No)	Yes	12.2	1.3-116	10.0	1.0-100	0.5	0.1-2.8	13.0	2.2-77.2	0.9	0.2-4.0
Physical exercises (Reference=1-15 years)	< 1 year	3.7	0.5-27.8	1.6	0.3-9.2	5.5	0.9-33.0	1.5	0.2-9.7	0.9	0.1-5.5
	> 15 years	2.9	0.4-21.1	1.2	0.2-7.2	3.5	0.6-20.2	3.1	0.5-19.9	3.2	0.4-23.3
Age: effect of	10 years	6.9	2.0-23.6	1.4	0.7-3.1	2.9	1.1-7.3	6.2	1.4-27.6	4.3	1.4-13.1

Likelihood ratio, $\chi^2 = 55.3$, 56 *df*, $P = 0.5$.

occupations. Disabling back injury was also a significant factor for a higher mean score of symmetric disc degeneration and vertebral osteophytosis (Table 3). Noteworthily, the effects of possible or likely chemical exposure on some of the parameters of spinal pathology that were seen in univariate analyses were not evident on adjustment for age.

Back Pain and Sciatica in Relation to Other Variates

Loglinear modeling was used to identify the most important intercorrelations of the variates, especially with back pain experience. The best-fitting models to explain the frequency of back pain and sciatica showed an association with the occupational groups but no relationship to the pathologic parameters. To assess the strength of the association with physical loading, odds ratios were estimated for the occupational comparisons after separate control for the effects of each of the following variates: symmetric disc degeneration, anular ruptures, end-plate defects, vertebral osteophytosis, and facet osteoarthrosis. As an example, the adjusted odds ratios for back pain and sciatica for occupation comparisons are given in Table 4 with respect to anular ruptures. Furthermore, back pain tended to be commoner with the physically more loading occupations (test for progressive relation: $P < 0.001$). A similar but weaker trend was observed in the incidence proportions for sciatica ($P = 0.03$). For the other pathologic parameters, the range of the point estimates of the odds ratios for back pain was 1.4–2.7 for heavy work, 1.9–3.0 for driving work, and 0.1–0.2 for sedentary work when mixed work was taken as the reference category. In the case of sciatica, the odds ratios were 1.5–2.3 for heavy work, 1.0–1.4 for driving work, and 0.6–0.9 for sedentary work.

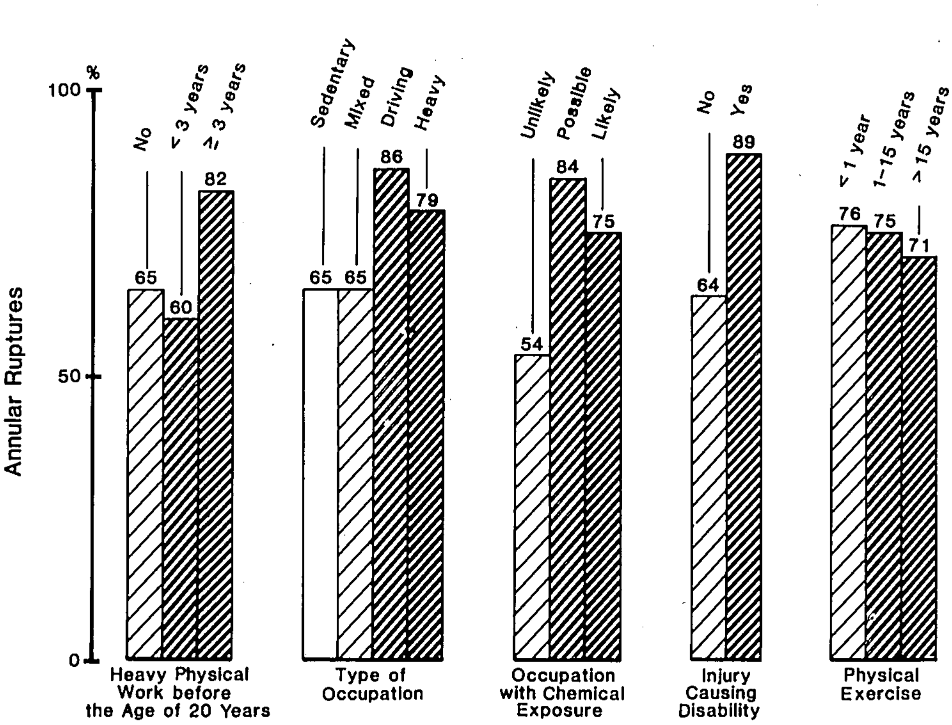

Fig 6. Occurrence of anular ruptures (Grade III or IV) in different categories of five occupational or physical loading determinants.

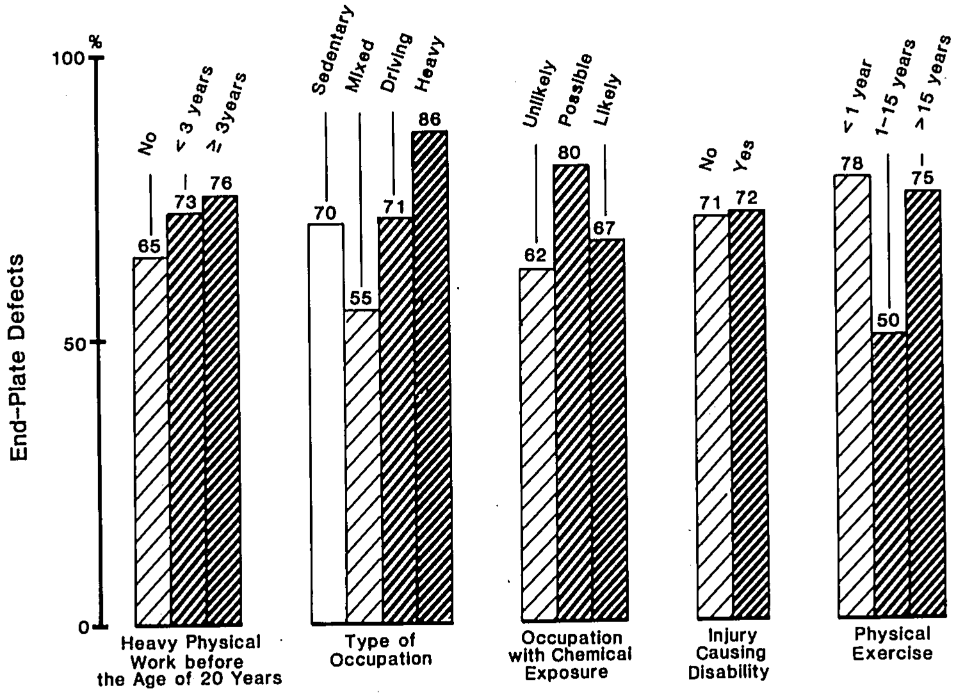

Fig 7. Occurrence of end-plate defects (Grade II or III) in different categories of five occupational or physical loading determinants.

DISCUSSION

Epidemiologic Aspects

This study appears to be the first project in which detailed pathologic data from the lumbar spine have been compared with a history of occupational and physical loading factors. We can offer the pathologic data with some confidence, as the methods have been successfully used on previous occasions. The doubts, inevitably, focus on the histories obtained from the families of the subjects.[37] Fortunately, practical experience of colleagues in the Institute of Occupational Health, Helsinki, could be relied on when the questions were formulated. The reliability of the answers is therefore unlikely to differ substantially from that of other, more direct questionnaire data. Indeed, the data on back pain occurrence do not differ materially from those of The Munkfors investigation.[17] It does, however, mean that the sample was not only restricted to subjects with a family, but also to those whose wives and families were willing and knowledgeable enough to answer.

A further aspect of selection was that all the subjects were of working

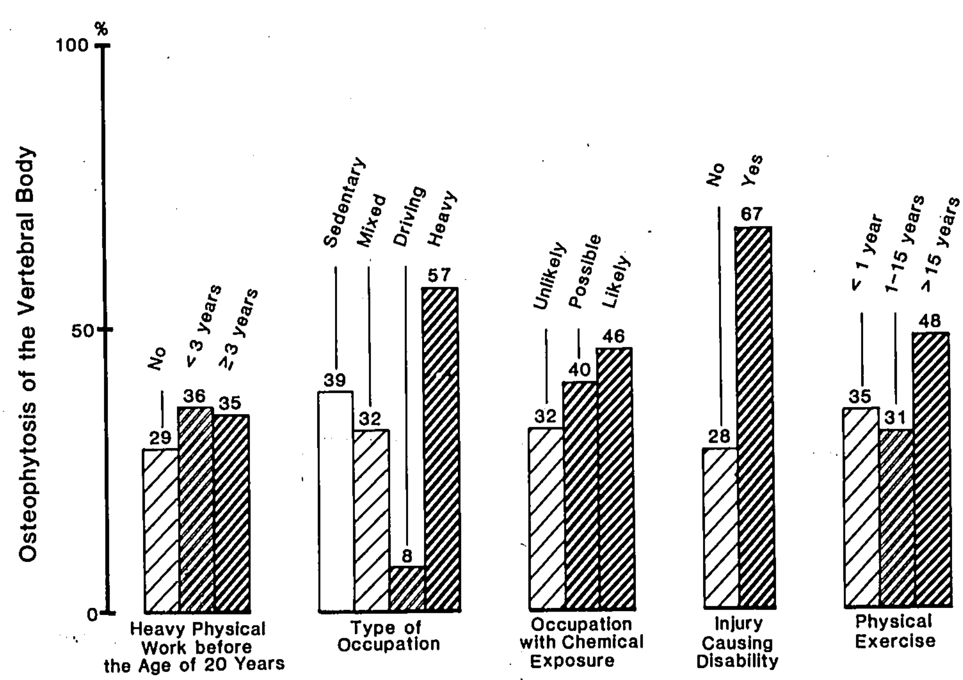

Fig 8. Occurrence of osteophytes of the vertebral body (Grade II or III) in different categories of five occupational or physical loading determinants.

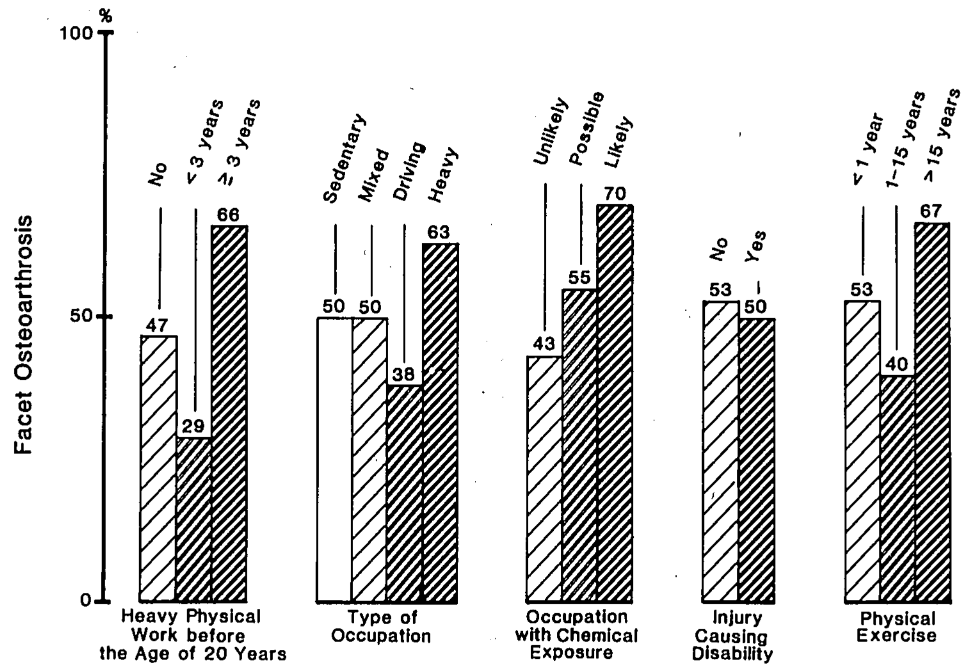

Fig 9. Occurrence of apophyseal intervertebral joint osteoarthrosis (Grade II or III) in different categories of five occupational or physical loading determinants.

Table 3. Least Squares Means (Mean) and Their Statistical Significance (*P*) from the Analysis of Covariance for the Class Variates in Relation to Symmetric Disc Degeneration, End-Plate Defects, and Vertebral Osteophytosis

	Covariate	*Classification*	*Mean*	*Effect/Contrast*	*P*
Symmetric disc degeneration	Injury with disability	No	1.7	Main	0.004
(scale, 0-III)		Yes	1.9	No versus yes	0.05
		Missing	2.3		
	Physical exercise	< 1 year	2.1	Main	< 0.05
		> 1 year	1.8		
Vertebral osteophytosis	Injury with disability	No	0.54	Main	0.04
(scale, 0-III)		Yes	0.93	No versus yes	0.01
		Missing	0.68		
Lower end-plate defects	Type of work	Sedentary	0.86	Main	0.02
(scale, 0-III)		Mixed	0.68	Mixed versus others	0.01
		Driving	0.93	Mixed versus heavy	0.002
		Heavy	1.1		
Upper end-plate defects	Type of work	Sedentary	0.97	Main	0.004
(scale, 0-III)		Mixed	0.71	Mixed versus others	0.002
		Driving	1.3	Mixed versus driving	0.0008
		Heavy	1.2	Mixed versus heavy	0.005

The effect of age (continuous variate) was significant for all the pathologic outcomes. Other covariates are shown only if their main effect (*F*-value) was significant at least at the 5% level. The exclusion of the nonsignificant covariates from the model did not change the estimates of the means of the final model terms.

Table 4. Odds Ratios (OR) and their 95% Confidence Intervals (95% CI) for Back Pain and Sciatica in the Occupational Comparisons Derived from Loglinear Models* Involving Anular Ruptures

Occupational comparisons	*Back pain*		*Sciatica*	
	OR	*95% CI*	*OR*	*95% CI*
Heavy versus mixed	2.7	(1.1-6.2)	1.9	(0.9-4.3)
Driving versus mixed	2.3	(0.8-6.2)	1.2	(0.5-3.4)
Sedentary versus mixed	0.14	(0.03-0.7)	0.7	(0.2-1.9)

Model involving back pain: Likelihood ratio $\chi^2 = 20.4$, 31 *df*, $P = 0.93$.
Model involving sciatica: Likelihood ratio $\chi^2 = 28.7$, 31 *df*, $P = 0.58$.
*Model variates: back pain/sciatica; age; occupation; anular ruptures; back pain × anular ruptures; occupation × anular ruptures; age × anular ruptures; occupation × back pain.

age and died after a brief illness. But the alternative, ie, inclusion of chronic illness and the age of retirement, would have widened the time gap between occupational exposure and pathologic outcome.

Two problems pervaded the analysis of the epidemiologic data. One was ignorance of the temporal pattern of development of the pathologic changes, and the other was that, owing to premature death, the development was incomplete.[30] To alleviate these time-related problems, the multivariate models included age at death as a covariate even though it had the same distribution in the occupational groups. Aging is the major determinant of degenerative conditions, but the exact time of occurrence could not be known with the used study design. The exclusion of cases of death due to chronic or infectious disease or of men on sickness pensions also reduced the effects of competing risks.

The third problem was that the estimation of the odds ratio derived from the logistic model may have been substantially biased, as the lifetime risk of degenerative diseases is often greater than 50%. If, however, the study population was stable (ie, one in which the distributions of all variables of interest, including exposure, do not change over the risk period), then the odds ratio will have estimated the incidence–density ratio.[12] But it is questionable, for instance, whether the exposed population at risk left employment because of degenerative disease at a rate similar to that of the nonexposed persons. At least the back pain and injury disability rates were dissimilar across the occupational classes. Conversely, the overall rate was less than 10%, and this figure is probably too low to bias the comparisons. Nevertheless, the stability of the study population with respect to possible selection processes remains a somewhat unsettled question.

Back Pain Occurrence

The incidence proportion of back pain in the occupational groups differed mainly in the mixed occupations, in which back pain and sciatica were the least common. No comparisons with previous studies can be made, however, because the concept of jobs that are a combination of light and heavy appears not to have been deliberately used. Nevertheless, with loglinear modeling, it was possible to control for one of the spinal pathology parameters when a history of back pain was related to the heaviness of the work. None of the radiographic or osteologic parameters that were used accounted for the differences in back pain history within the occupational groups. Instead there was a progressive relation between back pain and sciatica and the physical loading of the work, the least pain occurring for sedentary work and the most pain for heavy or driving work. This finding could be explained by pain production from slight, moderate, or severe pathologic changes when a person is subjected to loading.

In the univariate analysis, anular ruptures appeared to be consistently related to symptoms, ie, to back pain itself, sciatica, and consequent disability. In contrast, end-plate defects appeared to be wholly independent of symptoms, as was symmetric disc degeneration, osteophytosis, and facet osteoarthrosis. However, the loglinear modeling showed that even the relation of anular ruptures to symptoms was not statistically significant. Nonetheless, in patients during discography, anular ruptures would be a predictable source of back pain.[31] But the occurrence and severity of the pathologic changes in the subjects at the time they experienced their back pain remains unknown. It is notable that, of the back pain parameters, sciatica was no more associated with anular ruptures than the total back pain experience, but this finding may have stemmed from the method of data collection.

Physical Loading

Porter[34] compared the diagnoses in two groups of men attending a back pain clinic (445 miners who had started heavy work after leaving school or who had worked underground for at least 5 years and 977 non-miners). Prolapsed intervertebral disc was commoner in the non-miners, the miners having relatively more lateral canal stenosis or symptoms of neurogenic claudication. He concluded that the disc might be strengthened by heavy work when a person is young. Bioengineering studies then showed that the compressive strength of lumbar vertebrae and their resistance to bending movements in young men were related to the intensity of the men's physical exercise activity[35] and was basically a normal biologic adaptation.

In our study, heavy physical work for more than 3 years before the age of 20 years appeared to lead to more facet osteoarthrosis. But, as Figure 9 shows, the 'J-shape' indicated that if a person does no physical work in this period of development, that person is not without risk. A very similar situation was found for physical exercise after 20 years of age. However, the J-shape phenomenon with physical exercise after 20 years of age applied also to symmetric disc degeneration and end-plate defects, but not to anular ruptures. Thus, there is no major conflict between our results and those of Porter.[34]

Anular ruptures were more extensive in the men with a history of injury. This finding applied also to symmetric disc degeneration and vertebral osteophytosis, but not to end-plate defects or facet osteoarthrosis. These results might suggest a paradox, given that compressive overload leads to fracture of the end-plate[33] and, if repeated, to disc degeneration.[3] But injury, as reported for our study, may well refer to torsional or shear stress that is more likely to damage the anulus, although the hypothesis that torsional injury may damage the facets[6,7] is unsupported by these results.

Occupational and Other Risk Indicators

Symmetric disc degeneration, vertebral osteophytosis, and facet osteoarthrosis appeared to be related to the likelihood of chemical exposure. However, this relation was probably due to age differences between the exposed and unexposed subjects. Connective tissue metabolism is complicated and, in theory, can be disturbed by acids, alkalis, solvents, pesticides, heavy metals, etc., eg, by arsenic exposure[49] or exposure to chemicals used for vinyl chloride polymerization.[11] In any case, no conclusions can be drawn concerning the possible effects on the spine without proper investigation, identification of the chemicals, and control for confounding factors. Smoking was unfortunately not recorded because, at the time this study was planned, smoking had not yet been assessed as an important risk indicator for disc pathology.

The J-shape was evident for the physical heaviness of the subject's work in terms of symmetric disc degeneration and vertebral osteophytosis but was less obvious for end-plate defects and facet osteoarthrosis and did not at all for anular ruptures. For sedentary work, the most closely related risk was symmetric disc degeneration. For heavy work it was vertebral osteophytosis.

Driving seemed to be associated with the least symmetric disc degeneration, vertebral osteophytosis and facet osteoarthrosis, all three being degenerative in character. It might be suggested that the motion of the vehicle is actually an aid to diffusion, disc nutrition depending on movement.[16,50] The relation between driving and back pain is consistent with the data of earlier reports. The overrepresentation of anular ruptures in driving occupations, which was confined to the lower intervertebral levels, is not wholly at variance with the reports of Kelsey and Hardy[20] or Heliövaara.[13] As in their studies, no attempt was, or could be, made to distinguish the other physical loading factors included in driving occupations. In addition to torsional and lifting injuries to which some drivers are exposed, postural stress remains a likely cause of back pain due to driving.

Mixed occupations have a number of apparent advantages, the primary one being the lack of significant associations with any of the pathologic features observed. Mixed work therefore was consistently lower in risk than either heavy or sedentary work.

CONCLUDING REMARKS

Our hypothesis that fewer pathologic changes in the lumbar spine would be found in persons whose physical loading fell between the extremes was by no means disproved, nor was it definitely confirmed. But the 'J-shape' appeared for several of the results, and in several cases statistically significant relation was found, enough in fact to offer circumstantial evidence in support of our hypothesis. Back injuries and sedentary or heavy work contributed to the development of pathologic findings in the spine. Conversely, the severity of back pain was related to the heaviness of work. In other words, work-related factors may be responsible both for the development of pathologic changes and for the production of pain.

The study was unique and is unlikely to be repeated. The question remains of how the results can be confirmed and amplified. The most likely approach lies in the use of nuclear magnetic resonance, whose images serve to differentiate some, if not all, of the component features of disc pathology. The technique is applicable to longitudinal studies of people or occupational groups at risk, providing that their physical work load is clearly defined.

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Address reprint requests to

Prof. Tapio Videman
Institute of Occupational Health
Topeliuksenkatu 41 a A
SF-00250 Helsinki
Finland

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Appendix A1. Degree of Symmetric Disc Degeneration in Relation to Intervertebral Disc Level in the Different Occupational Groups

Type of work	*Degree of degeneration*	*Level of intervertebral disc* L1-2	L2-3	L3-4	L4-5	L5-S1
Heavy	0	0	2	2†	0‡	2
	I	7	8	7	7	4
	II	2	5	9	8	6
	III	0	6	10	13	12
Driving	0	0	4§	2	0	0
	I	7	8	7	2	3
	II	1	0	2	8	6
	III	0	0	3	4	4
Sedentary	0	0	2	4	2	3
	I	5	10	4	4	3
	II	2	2	6	5	5
	III	1	3	6	9	9
Mixed	0	2	2	2	4	1
	I	4	9	12	3	4
	II	1	4	5	6	4
	III	0	3	1	5	8
Total no. of discs		32	68	82	80	74

*See Figure 1A for an explanation of the scale.
Test for trend:
†$P = 0.009$ (Heavy versus mixed, L3-4).
‡$P = 0.07$ (Heavy versus mixed, L4-5).
§$P = 0.015$ (Driving versus mixed, L2-3).

Appendix A2. Degree of Anular Rupture in Relation to the Intervertebral Level in the Different Occupational Groups

Type of work	*Degree of anular rupture**	*Level of intervertebral disc* L1-2	L2-3	L3-4	L4-5	L5-S1
Heavy	0	0	5	6†	1‡	2
	I	5	6	5	4	3
	II	3	6	6	10	7
	III	1	4	11	13	12
Driving	0	2	4§	2	1	1
	I	5	8	7	2	1
	II	0	0	2	4	3
	III	1	0	3	7	8
Sedentary	0	1	3	4¶	2	5
	I	5	9	4	4	2
	II	2	4	2	2	3
	III	0	1	10	12	8
Mixed	0	2	3	4	5	2
	I	3	9	12	0	5
	II	1	3	3	7	3
	III	1	3	1	5	7
Total no. of discs		32	68	82	79	72

*See Figure 1B for an explanation of the scale.
Test for trend:
†$P = 0.02$.
‡$P = 0.08$.
§$P = 0.04$.
¶$P = 0.02$.

Appendix A3. Degree of Defects in Relation to the Level of the Intervertebral End-Plate (Upper/Lower) in the Different Occupational Groups

Type of work	Degree of end-plate defect*	Level of intervertebral end-plates (upper/lower) L1-2	L2-3	L3-4	L4-5	L5-S1
Heavy	0	0/4	5/5	8†/10‡	3/7§	5¶/8
	I	6/3	12/9	8/8	19/12	11/11
	II	3/2	1/6	7/8	5/4	6/3
	III	0/0	3/1	5/4	1/4	1/0
Driving	0	1/3	2‖/7	2/6	1**/3††	2‡‡/2
	I	7/4	5/4	10/7	9/6	6/10
	II	0/0	2/1	1/0	2/4	3/1
	III	0/1	3/0	1/1	2/1	2/0
Sedentary	0	3/6	9/8	5/9	2/7	5§§/4
	I	4/2	7/7	11/7	14/8	7/10
	II	1/0	0/2	3/2	4/5	3/2
	III	0/0	1/0	1/2	0/0	3/1
Mixed	0	3/5	6/8	9/14	5/10	10/5
	I	2/1	10/6	9/5	10/5	5/10
	II	1/1	2/3	1/0	3/3	2/2
	III	1/0	0/1	1/1	0/0	0/0
Total		32/32	68/68	82/82	80/79	71/69

*See Figure 1C for an explanation of the scale.
Test for trend:
†$P = 0.04$.
‡$P = 0.01$.
§$P < 0.05$.
¶$P = 0.02$.
‖$P = 0.03$.
**$P = 0.09$.
††$P = 0.05$.
‡‡$P = 0.01$.
§§$P = 0.03$.

Appendix A4. Degree of Vertebral Osteophytosis in Relation to the vertebral Level in the Different Occupational Groups

Type of work	Degree of osteophytosis*	Level of vertebra L1	L2	L3	L4	L5
Heavy	0	2	15	16	13	12
	I	0	1	5	5	6
	II	0	2	5	6	6
	III	0	0	2	4	4
Driving	0	4	8	8	6	7
	I	0	2	3	6	6
	II	0	0	0	0	0
	III	0	0	1	1	0
Sedentary	0	4	10	13	10	8
	I	1	1	5	4	7
	II	0	2	0	1	2
	III	0	0	0	3	1
Mixed	0	3	11	12	10	10
	I	0	2	4	4	4
	II	1	2	3	5	4
	III	0	0	0	0	1
Total		15	56	77	78	78

*See Radiography under Cadaveric Specimens in the Materials and Methods section for an explanation of the scale.

Appendix A5. Size of Facet Joint Osteophyte in Relation to the Level of Facet Joint in the Different Occupational Groups

Type of work	Size of osteophytea (mm)	Level of facet joint (left/right)				
		L1-2	L2-3	L3-4	L4-5	L5-S1
Heavy	-2	5/4	[a]9/10	6/4	4/6[b]	12/8
	3-4	4/6	10/8	7/11	10/10	7/6
	5-6	1/0	2/3	10/6	7/3	2/4
	7-8	0/0	0/0	3/1	1/2	2/1
	9-	0/0	0/0	0/0	1/0	1/1
Driving	-2	3/2	1/2	0/4	5/2	4/3
	3-4	0/1	5/3	7/2	2/3	2/3
	5-6	0/0	0/1	1/1	0/1	0/1
	7-8	0/0	0/0	0/0	0/1	0/0
	9-	0/0	0/0	0/0	1/1	1/0
Sendentary	-2	6/5	10/5	6/2	5/2	11/2
	3-4	1/2	2/5	9/12	9/9	5/5
	5-6	0/0	0/2	2/3	2/4	0/4
	7-8	0/0	0/0	1/0	2/2	0/1
	-9	0/0	0/0	0/0	0/0	2/1
Mixed	-2	4/2	3/6	4/5	4/3	6/6
	3-4	1/3	4/1	2/2	5/6	3/6
	5-6	0/0	3/2	7/3	2/2	2/1
	7-8	0/0	1/1	1/2	2/1	2/0
	-9	0/0	0/1	1/2	3/4	1/1

Test for trend:
*$P = 0.08$.
†$P = 0.08$.