Airway symptoms and lung function in pipelayers exposed to thermal degradation products from MDI-based polyurethane

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Abstract

Objectives—To study the prevalence of symptoms from the eyes and the upper and lower respiratory tract, lung function, and immunological sensitisation towards isocyanates in pipelayers exposed to thermal degradation products from methylene diphenyl diisocyanate (MDI)-based polyurethane (PUR).

Material and methods—50 presently active and 113 formerly active pipelayers were examined. Also, 65 unexposed workers were investigated for comparison. The one year prevalence of symptoms and smoking history (questionnaire data), lung function (vital capacity (VC) and forced expiratory volume in one second (FEV₁), and atopy (positive skin prick tests towards standard allergens) were assessed among pipelayers and controls. For the pipelayers, the presence of work related symptoms and estimates of isocyanate and welding exposure were obtained from an interview. Skin prick tests towards specific isocyanate antigens and determinations of IgE-MDI and IgG-MDI in serum were also performed.

Results—The prevalence of episodes (more than once a month) of irritative eye symptoms, congestion of the nose, and soreness or dryness in the throat was much higher among the PUR pipelayers than among the controls. Most of the pipelayers with symptoms reported that these had started and occurred in relation to the PUR welding tasks. Presently active pipelayers with recent high PUR exposure showed a significant reduction of FEV₁ compared with the controls. The estimated reduction, adjusted for smoking, was -0.3 l (P=0.04). There was no confounding effect of ordinary welding. None of the pipelayers showed positive skin prick reactions against the specific isocyanate antigens used, or positive IgE-MDI, and only two had increased IgG-MDI.

Conclusions—The findings indicate that exposure to thermal degradation products from MDI-based polyurethane has adverse effects on the mucous membranes and airways.

Keywords: methylene diphenyl diisocyanate; respiratory disease; construction industry

Isocyanates are agents responsible for a substantial proportion of occupational asthma.¹ In industrial handling, methylene diphenyl diisocyanate (MDI) has been considered to have a low potential in inducing respiratory disease compared with other isocyanates, because of its low vapour pressure. However, especially in connection with spraying or heating, MDI has been associated with asthmatic, as well as systemic reactions.² ³ The pathogenetic mechanisms are still controversial; irritant, immunological and pharmacological mechanisms have been suggested, and may well coexist. Moreover, irritative conjunctival and upper airway symptoms may also be prevalent after exposure to MDI,²³ but have aroused less interest.

In the present study we examined pipelayers who had been welding district heating pipes insulated with polyurethane (PUR) foam. This foam is a complicated structure formed by polymerisation of a mixture of reagents mainly containing 4,4’-MDI, 2,2’-MDI, 2,4’-MDI, and polyethers with one or two hydroxy groups. If the foam is not thoroughly removed from the mild steel pipe before welding, the pipelayers are exposed not only to the welding fumes but also to thermal degradation products from the foam. These products include numerous different isocyanates, amino-isocyanates and amine compounds.³ Workplace monitoring with a filtertape instrument has indicated considerable exposure (M Dalene, personal communication). A biomarker, 4,4-methyleneedianiline, has been used to assess isocyanate exposure among these pipelayers.⁴ In the present study the aims were to investigate the prevalence of symptoms from the eyes and the upper and lower respiratory tract, and lung function. Further, immunological tests were performed to detect possible sensitisation.

Material and methods

PIPELAYERS: STUDY GROUP AND EXPOSURE

Thirty one companies engaged in PUR pipelaying in the south of Sweden were identified from telephone directories and from suppliers of pipes. From all but one, we obtained lists of present and former employees who had ever participated for at least four weeks in such work. Information on the study was sent to each subject, together with a short enquiry on work related symptoms, duration of work with PUR, and smoking. The entry criteria were met by 228 men, of whom 163 (71%) participated in the total examination; for the remain-
Table 1  
Age, smoking habits, and exposure among pipelayers and controls

<table>
<thead>
<tr>
<th>Subjects (n)</th>
<th>Presently active</th>
<th>Formerly active</th>
<th>Controls</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>113</td>
<td>65</td>
<td></td>
</tr>
<tr>
<td>38 (25, 53)</td>
<td>49 (35, 61)</td>
<td>41 (22, 59)</td>
<td></td>
</tr>
</tbody>
</table>

Age*  874

Smoking habits:
Lifelong non-smoker (n (%))
- 18 (36) 25 (22) 34 (52)
- 19 (38) 59 (52) 100%

Pack-years*
- 14 (2, 27)
- 14 (2, 33)

Age at start of smoking*
- 16 (15, 21)
- 17 (14, 20)

Current smoker (n (%))
- 13 (26)
- 29 (26) 31 (48)

Pack-years*
- 12 (1, 33)
- 21 (4, 40) 14 (5, 37)

Age at start of smoking*
- 16 (13, 19)
- 17 (15, 20) 17 (13, 21)

PUR welding:
Start, calendar year*
- 1974 (1968, 1984)

Cumulative working days*
- 755 (240, 2710)
- 340 (40, 2820)

Working days past month*
- 7.8 (0, 20)

End of exposure*
- —
- 1988 (1979, 1991)

Ordinary welding:
Start, calendar year*
- 1959 (1948, 1974)

Cumulative working days*
- 1928 (0, 5390)
- 2690 (930, 5280)

Presently exposed (n (%))
- 32 (73)
- 83 (64)

Working days past month*
- 7.5 (0, 20)
- 5 (0, 20)

* Median (10th, 90th percentile).

ing 65 men we obtained a response to the enquiry from 41.

Exposure data were obtained from a questionnaire and at a personal interview (see below for details). Fifty men (31% of the participants) had been engaged in PUR pipelaying during the three months immediately preceding the examination day. These men formed a subset of presently active PUR pipelayers. The remaining 113 men are here called formerly active PUR pipelayers. Of these, 89 men were still working as pipelayers, whereas 24 men had left the profession six months or more before the investigation.

The presently active PUR pipelayers were further subdivided into one group with recent high exposure—that is, >10 working days of PUR welding during the month preceding the examination (n=19; median 20 work days)—and one group with recent low exposure—that is, ≤10 work days, (n=31; median 0 work days).

Table 1 gives descriptive data on exposure for all participating pipelayers. The presently active PUR pipelayers had a higher estimate for lifetime cumulative days of PUR welding than the formerly active men, but a lower estimate for cumulative days of ordinary welding. Within the group of presently active PUR pipelayers a similar difference was noted; those with recent high exposure had as a median 1640 (10th, 90th percentile 390, 3920) lifetime PUR welding days, whereas the group with recent low exposure had 500 (130, 1740) such days. The corresponding estimated cumulative working days with ordinary welding were 190 (0, 2100) and 2400 (480, 5900) respectively. Even though men with recent high exposure were younger than those with recent low exposure (33 (22, 53) vs. 44 (25, 53) years), the median duration of PUR exposure was similar (11 years in both groups).

The examination took place at the end of 1991 and the beginning of 1992. Shortly afterwards, many pipelayers terminated their work because of a crisis in the building sector. Hence, in 1993 the questionnaire was once again sent to the group of 50 presently active PUR pipelayers, and was returned by 44 of them. Seventeen were still active in PUR work, whereas 27 had finished work. These groups did not differ with respect to age. Data obtained in 1991–2 indicated that these groups had similar tobacco consumption, whereas the men still active in 1993 had higher cumulative exposure to PUR (825 (280, 4000) days) compared with those who had finished working (645 (192, 2622) days).

Generally, there were two main categories of PUR pipelayers. One category consisted of pipelayers almost exclusively engaged in the construction of district heating pipe systems. Often they were employed in small companies, specialised in this type of job. At the time of investigation about 40% of the presently active PUR pipelayers were of this type.

For the rest, the main type of work task was mixed pipelaying and plumbing, including the welding of ordinary non-insulated pipes. Now and then they used PUR insulated pipes, when connecting the internal pipe system of a building with the district heating pipe system. In the 1970s, when district heating pipe systems were first installed in many communities, PUR pipelaying occurred more often than nowadays for several of these men.

Earlier work practices often included the burning off of the foam insulation by a gas torch before welding; such practices were reported by one third of the pipelayers in our study. Later on, careful manual removal of at least 25 cm of the foam before welding was recommended. Either gas or manual metal arc welding was used. The use of personal protection devices had been very limited; only 7% of the men reported that they often or always used a half mask respirator. Foaming at the junction sites after welding was usually performed by specialised workers not included in the present study, but 15% of the pipelayers reported that they often or always used to foam MDI-based PUR.

**CONTROLS**

During the same time period as the pipelayers were examined, we investigated the meta-
choline reactivity in a working population, not presently exposed to airway irritants. This population included both blue and white collar workers from a pharmaceutical company, companies producing medical equipment and printed matters, shop assistants, postmen, paramedics, and radiology technicians. Volunteers were recruited, the only exclusion criteria being “almost daily use of asthma medications or use of peroral cortisone medication for any other reason”

**QUESTIONNAIRES**

A detailed questionnaire was sent by mail to all participants (pipelayers and controls) about two weeks before the examination. Major respiratory symptoms (dyspnoea, wheezing, and cough; translated from the British Medical Research Council questionnaire

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family allergy, previous pulmonary or cardiac disease, and questions directed at symptoms indicative of non-specific bronchial hyperreactivity were recorded. A lifetime employment history was reported, as were exposures to specified dusts, chemicals, and contact with animals during work or leisure time. The questionnaire also consisted of additional questions on the prevalence and frequency of specified symptoms from the eyes, nose, throat, and chest. Symptoms during the past year and earlier in adult life (for the pipelayers explicitly stated as the period before PUR pipelaying started) were recorded separately.

A detailed smoking history was also obtained from the questionnaire. The smoking habits among the pipelayers cannot be directly compared with those among the controls, as ex-smokers were excluded by definition from the second group. However, the daily amount of tobacco smoked was similar among active smokers, regardless of exposure state (table 1).

INTERVIEW
In a standardised interview at the examination a trained occupational health nurse (KKD) obtained information from the pipelayers about their detailed work history and their work habits during pipelaying and welding operations. Thus, the lifetime cumulative number of working days and the number of working days with welding of PUR pipes and welding of other pipes (also including other welding experiences) could be calculated. The corresponding figures were obtained for the preceding three months and one month. Days with part time work with a certain task were converted to eight hour working days. Supplementing questions on specific symptoms from the eyes, nose, throat, and chest, and their relation to PUR welding were also asked, without regard to noted respiratory complaints in the self-administered questionnaire.

SKIN PRICK TEST AND ASSAYS OF SPECIFIC IMMUNOGLOBULINS E AND G
For pipelayers and controls a skin prick test with 13 standard extracts (ALK, Copenhagen), a positive (histamine, 3 Hep), and a negative control was performed. For the pipelayers additional skin prick tests with isocyanate conjugates with human serum albumin were added. The specific isocyanates used were 4,4′-MDI (which is normally the main component in technical grade MDI), toluene diisocyanate (commercial grade; 2,4- and 2,6-isomers), phenylisocyanate, p-toluene monoisocyanate, and 1,6-hexamethylene diisocyanate. The wheal size and shape were recorded on a transparent tape after 15 minutes. A wheal that was at least half the size of the histamine wheal was scored as positive. Atopy was defined as a positive skin reaction to at least one of the standard extracts. There was no difference between the PUR pipelayers and the controls in the prevalence of atopy (22% vs 25%).

Radio allergosorbent test (RAST) and enzyme linked immunosorbent assay (ELISA) tests for specific IgE and IgG antibodies respectively, against MDI conjugates with human serum albumin were also performed, including serum samples from 49 of the controls. For IgE-MDI, specific binding >0.3% was considered positive (highest control 0.1%). For IgG-MDI, values exceeding the highest value in the controls (IgG-MDI 0.14 A) were regarded as positive.

LUNG FUNCTION TEST
Vital capacity (VC) and forced expiratory volume during one second (FEV₁) were determined before and 15 minutes after administration of a β-agonist (two inhalations of Bricanyl Turbohaler). The lung function tests were performed as recommended by the American Thoracic Society, using a Vitalograph. The same test procedure was used for pipelayers and controls. The exposure state was not blinded for the technician performing the test. The VC and FEV₁ were expressed as % predicted, using an external reference equation. Metacholine reactivity was also investigated (results not reported here).

STATISTICS
The prevalence odds ratio (POR), adjusted for potential confounders was used for measuring the effect of exposure to PUR. The focus of interest was on the one year prevalence of different types of symptoms. Effect estimations were performed by logistic regressions. Age (<45, >45 years), atopy (yes, no), and smoking (lifelong non-smoker, ex-smoker, smoker) were considered. Several categorical exposure variables were explored. The categorisations are as follows: exposure state (PUR piplayer, control), present exposure state (presently active, formerly active), cumulative days for PUR welding (≤500, >500), cumulative days for ordinary welding (≤2500, >2500), days with PUR welding last month, ≤10, >10), years since end of PUR welding (0.25-5, >5). For the lung function variables linear regressions, adjusted similarly for potential confounders, were performed. Here, age was treated as a continuous variable. Ex-smokers were omitted from the analyses when pipelayers and controls were compared, whereas they were included in the internal comparisons.

For statistical testing we used Fisher’s exact test for binary variables, and the Mann-Whitney U test for continuous variables. All tests were two tailed. The different statistical methods were performed as generally described.

RESULTS
SYMPTOMS
The prevalence of episodes (more than once a month) of irritative eye symptoms, congestion of the nose (blocked nose), and soreness or dryness in the throat (throat irritation) during the year preceding the examination was much higher among the PUR pipelayers than among the controls (table 2). This was especially pronounced among the non-smokers. Also, the pipelayers reported a higher prevalence of symptoms from the lower Airways, such as pro-
Table 2  Symptoms during the year preceding the examination among PUR pipelayers and controls (questionnaire data)

<table>
<thead>
<tr>
<th>PUR pipelayers</th>
<th>Controls</th>
<th>Pipelayers v controls</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Non-smokers (n=43)</td>
<td>Ex-smokers (n=78)</td>
</tr>
<tr>
<td>Eye irritation*</td>
<td>11 0.26</td>
<td>16 0.21</td>
</tr>
<tr>
<td>Blocked nose*</td>
<td>12 0.28</td>
<td>14 0.18</td>
</tr>
<tr>
<td>Throat irritation*</td>
<td>10 0.23</td>
<td>6 0.08</td>
</tr>
<tr>
<td>Dry cough*</td>
<td>6 0.14</td>
<td>10 0.13</td>
</tr>
<tr>
<td>Productive cough†</td>
<td>3 0.07</td>
<td>8 0.10</td>
</tr>
<tr>
<td>Attacks of wheezing or dyspnoea‡</td>
<td>6 0.14</td>
<td>23 0.29</td>
</tr>
</tbody>
</table>

* Episodes more often than once a month.
† On most days for more than three months.
‡ Ever such episodes.

PR = prevalence ratio; POR = prevalence odds ratio; from a logistic regression, controlling for age, atopy, and smoking habits (ex-smokers excluded).

Table 3  Prevalence of symptoms during the year preceding the examination among presently active and former PUR pipelayers (questionnaire data)

<table>
<thead>
<tr>
<th></th>
<th>Presently active</th>
<th>Formerly active</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Recent high exposure (n=19)</td>
<td>Recent low exposure (n=31)</td>
</tr>
<tr>
<td>Eye irritation*</td>
<td>0.37</td>
<td>0.32</td>
</tr>
<tr>
<td>Blocked nose</td>
<td>0.37</td>
<td>0.26</td>
</tr>
<tr>
<td>Throat irritation*</td>
<td>0.32</td>
<td>0.13</td>
</tr>
<tr>
<td>Dry cough*</td>
<td>0.16</td>
<td>0.16</td>
</tr>
<tr>
<td>Productive cough†</td>
<td>0.16</td>
<td>0.13</td>
</tr>
<tr>
<td>Attacks of wheezing or dyspnoea‡</td>
<td>0.32</td>
<td>0.19</td>
</tr>
</tbody>
</table>

* Episodes more often than once a month.
† On most days for more than three months.
‡ Ever such episodes.

PR = prevalence odds ratio, obtained from a logistic regression, controlling for age, atopy, smoking habits, and cumulative exposure (PUR and other welding).

Table 4  Relation between symptoms and PUR pipe laying among 163 pipelayers (interview data)

<table>
<thead>
<tr>
<th></th>
<th>No symptoms at work</th>
<th>Symptoms appearing immediately</th>
<th>Symptoms appearing in the evening*</th>
<th>Better on weekends</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eye irritation</td>
<td>114</td>
<td>41</td>
<td>8</td>
<td>42</td>
</tr>
<tr>
<td>Blocked nose</td>
<td>134</td>
<td>17</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Throat irritation</td>
<td>130</td>
<td>28</td>
<td>5</td>
<td>28</td>
</tr>
<tr>
<td>Dry cough</td>
<td>144</td>
<td>17</td>
<td>2</td>
<td>17</td>
</tr>
<tr>
<td>Attacks of wheezing or dyspnoea</td>
<td>141</td>
<td>14</td>
<td>8</td>
<td>16</td>
</tr>
</tbody>
</table>

* Or immediately and in the evening.

Table 5  Prevalence of symptoms during the preceding year in 1991-2 and in 1993 in relation to exposure state 1993 among 44 PUR pipelayers, who were all active in 1991-2 (questionnaire data)

<table>
<thead>
<tr>
<th>Questionnaire 1991-2</th>
<th>Questionnaire 1993</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active 1993 (n=17)</td>
<td>Not active 1993 (n=27)</td>
</tr>
<tr>
<td>Eye irritation*</td>
<td>0.41</td>
</tr>
<tr>
<td>Blocked nose*</td>
<td>0.35</td>
</tr>
<tr>
<td>Throat irritation*</td>
<td>0.29</td>
</tr>
<tr>
<td>Dry cough*</td>
<td>0.18</td>
</tr>
<tr>
<td>Productive cough†</td>
<td>0.18</td>
</tr>
<tr>
<td>Attacks of wheezing or dyspnoea‡</td>
<td>0.17</td>
</tr>
</tbody>
</table>

* Episodes more often than once a month.
† On most days for more than three months.
‡ Ever such episodes.

thoracic symptoms (table 3). Logistic regression models, including age, atopy, and smoking habits in addition to present exposure status confirmed the findings, which, however, reached significance only for eye irritation. The prevalences of these symptoms decreased with increasing time since the end of PUR piping. In contrast, there was no difference in the prevalence of symptoms from the lower airways between presently or formerly active PUR pipelayers (table 3). In logistic regression models, the cumulative days of PUR welding and ordinary welding were explored, showing no significant associations with any type of symptoms. Nominally higher prevalences of symptoms were reported among presently active pipelayers with recent high, compared to those with recent low PUR exposure.

In the interview, most of the pipelayers with symptoms reported that these had started and occurred in relation to the PUR welding tasks (table 4). The non-atopic workers reported work related symptoms as often as the atopic workers; likewise there was no difference in the reports between workers with different smoking habits. The interval between start of PUR welding and the occurrence of any work related symptom was long, with a median 9 (2,20) years. Atopic workers did not report a shorter symptom free interval than did non-atopic workers.

Table 5 shows the results from the 1993 questionnaire. The symptom prevalences were stable over time.
SKIN PRICK TEST AND ASSAYS OF SPECIFIC IMMUNOGLOBULINS E AND G

None of the pipelayers showed positive skin prick reactions against the specific isocyanate antigens used or positive IgE-MDI. Two pipelayers showed low IgG-MDI values (0.18 and 0.30 A).

LUNG FUNCTION

Table 6 shows VC and FEV₁ (expressed as % predicted) among all pipelayers and controls. In multiple linear regression models (using the observed value, adjusted for smoking habits, age, and height) a small effect of exposure was found for FEV₁ (β=-0.1 l (P=0.10)) but not for VC (table 6). As expected, smoking effects were evident for both FEV₁ and VC.

Similarly, when presently active pipelayers were compared with controls, the corresponding effect for FEV₁ was β=-0.2 l (P=0.09). The effect was most pronounced among presently active pipelayers with recent high exposure to PUR, having an estimated reduction of FEV₁ of -0.3 l (P=0.04), compared to controls. The reduction among those with recent low exposure to PUR was less, (-0.1 l (P>0.2)). In the models, the estimated reduction among smokers was about -0.4 l (P<0.001). No confounding effect of ordinary welding could be demonstrated. For VC no differences between pipelayers and controls were evident.

In internal comparisons among the pipelayers, including also ex-smokers, there were no significant differences in FEV₁ and VC between presently and formerly active PUR pipelayers, adjusting for age, height, and smoking habits. We explored the effects of several other exposure indices (cumulative days of PUR welding, cumulative days of ordinary welding, time since end of PUR and ordinary welding) in further models, but no significant exposure-response relations were disclosed for any of them. Likewise, a similar internal comparison between men with recent high and recent low PUR exposure did not show significant differences in FEV₁.

NON-PARTICIPANTS

According to information from the initial short enquiry, or from the employer’s lists, the duration of PUR pipelaying was estimated to have been 1-12 months for 17 (26%) of the 65 non-participants, and >1 year for five (8%) of them. For the 163 participants the corresponding figures, as obtained from these sources, were 34% and 45%. Among the 41 non-participants who responded to the short initial enquiry three men (7%) reported work related symptoms from the eyes or nose, and five men (12%) reported work related airway symptoms. In contrast, among the participants the corresponding figures were 32% and 43% respectively.

Discussion

We have found that PUR pipelayers, compared with unexposed controls, experienced an increased prevalence of current irritative symptoms from the eyes, nose, and throat. They also reported that such symptoms occurred in direct relation to PUR welding. The prevalence of irritative symptoms was highest among the presently active PUR pipelayers, and decreased with increasing time since last PUR exposure. The same pattern emerged for productive cough. A direct irritating effect of thermal degradation products of MDI based PUR is the most likely explanation to these findings.

The presently active pipelayers with recent high PUR exposure had a reduced FEV₁, compared with controls. A reduction of FEV₁ also occurred in the total PUR pipelayer population, but it was weaker. Attacks of wheezing or dyspnoea, symptoms indicating airway obstruction, were nominally more prevalent among pipelayers than among controls, but not more prevalent among presently active pipelayers. When assessing the prevalence of respiratory symptoms and signs in a cross sectional study population, such as the subset of presently active pipelayers, a selection bias may be introduced, because workers with respiratory symptoms and signs may have left the PUR work task beforehand. This will lead to an underestimation of the true risk. This bias may be present in the direct comparisons between presently and formerly active pipelayers, but is reduced in the overall analyses in which formerly active PUR pipelayers are included.

An aggravation of respiratory symptoms from concomitant exposure to respiratory irritants at work and smoking may increase the tendency for smokers to quit their habit. We have reason to think that such interactions have affected our results, as we found four ex-smokers who had a clinical diagnosis of asthma during their work as PUR pipelayers, and one ex-smoker who had his asthma diagnosis while he was working as a pipelayer but before PUR welding started. All but one of them reported aggravated symptoms during PUR welding, whereas the remaining subject stated that ordinary welding was equally symptom provoking. Thus, this may have resulted in an underestimation of the true risk for symptoms and decreased lung function in the direct comparisons between pipelayers and controls, as all ex-smoking pipelayers were excluded. Four of the five ex-smoking asthmatic workers also belonged to the formerly active group. This

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Table 6 Lung function in pipelayers and controls

<table>
<thead>
<tr>
<th>Lung function, expressed as % predicted*</th>
</tr>
</thead>
<tbody>
<tr>
<td>VC</td>
</tr>
<tr>
<td>---------------</td>
</tr>
<tr>
<td>PUR pipelayers:</td>
</tr>
<tr>
<td>Non-smoker†</td>
</tr>
<tr>
<td>Smoker†</td>
</tr>
<tr>
<td>Controls:</td>
</tr>
<tr>
<td>Non-smoker†</td>
</tr>
<tr>
<td>Smoker†</td>
</tr>
<tr>
<td>Linear regression model‡:</td>
</tr>
<tr>
<td>Exposure stage§</td>
</tr>
<tr>
<td>Smoking§</td>
</tr>
<tr>
<td>Atopy§</td>
</tr>
</tbody>
</table>

* Reference equation from Berglund et al†:
† Median (10th, 90th percentile).
‡ Ex-smokers excluded; also for age, and height.
§ (l litres) (P value).
could partly explain why we found no clearcut
findings indicating a persisting adverse effect of
exposure to the lower airways.

The basis for recruitment to the study was
corporate reports of employees. We had no
possibility of investigating the completeness of
these reports. However, for men still active as
pipelayers or having related assignments, we
think that the losses should have been small, as
we recruited from all companies specialising in
PUR pipelaying, and all other major pipelaying
companies in the area. For pipelayers entirely
leaving their occupation there might be some
losses, which we cannot estimate. For identified
subjects who were non-participants, we
have some information, indicating less expo-
sure and less symptoms, than among partici-
pants.

Another bias which may be operating is a
selection of healthy persons to the occupation.
It was found that welders under the age of 30
had a higher FEV₁, than a group of controls.¹⁰
In this study we have no indications of a major
selection bias of this type. We did not find a
difference in the prevalence of atopy, or a
difference in the proportion of men with symp-
toms earlier in adult life or before PUR work
started when all PUR pipelayers and controls
were compared. We also found that VC and
FEV₁ among controls and formerly active PUR
pipelayers under the age of 35 were very close
data not given). In contrast, young presently
active PUR pipelayers showed a reduction of
FEV₁ compared with controls. This is again
comparable with an exposure effect.

Can we then attribute the excess of respira-
tory symptoms and decreased lung function in
the pipelayers to their exposure to thermal
degradation products from isocyanates? The
investigated pipelayers were exposed to a
complex mixture of compounds, several of which
are well known respiratory irritants or sensitis-
ers. High peak exposures to isocyanates and
amines occur at thermal decomposition of
technical quality MDI-based PUR, which in
itself has a complex isomeric composition, and
more complex and new isocyanate compounds
are formed.¹¹ Aldehydes and other compounds
are formed from the degraded polyol ingredi-
ent. Further, the gas or metal arc welding of
the mild steel pipes, which are sometimes coated
by a protective oil, yields various gaseous and
particulate air contaminants.¹² A recent over-
view of the literature on respiratory effects of
welding was presented by Sjögren and Ulfvar-
sön.¹³ The prevalence of chronic (simple)
bronchitis has repeatedly been increased
among welders. Data are, however, conflicting
as to whether non-smoking welders also have
an increased prevalence of chronic bronchitis.
Impaired spirometric values have been found
mainly for FEV₁. In some studies the effect was
seen only in smokers, in others non-smokers
have also been affected.¹⁴ Although the interest
in respiratory effects of welding fumes have
focused on the bronchi, it is evident that the
upper airways can also be affected. An
increased prevalence of symptoms from the
upper respiratory tract has been described,
with chronic rhinitis as the most often reported
symptom among shipyard welders.¹⁵

The outlined complexity of exposure indeed
merits caution in the internal comparisons. We
estimated the cumulative work days of PUR and
ordinary welding, based on the retrospec-
tive self reports. These estimates are by nature
subject to uncertainties. Time since last
exposure to PUR is probably more accurately
determined. We also presume that recent
working days can be accurately reported. Other
factors which could not be taken into account,
not least individual work habits, may greatly
influence the exposure to the thermal degrada-
tion products of MDI and the welding fumes.
We have previously shown, in this study base
of pipelayers, that the number of welded PUR
pipes during the preceding three months
(which closely parallels duration of such work)
correlates positively with 4,4-methyleneadi-
line in plasma, a biomarker for exposure.¹⁶ The
present study group consists of pipelayers with
varying intensity and duration of PUR pipelay-
ing and ordinary welding, a prerequisite for
separation of the effects, but our exposure
indices are crude. This may partly explain the
difficulties in showing exposure-response rela-
tions in the internal comparisons. However, in
the group of presently active pipelayers it was
obvious that the group with recent high
exposure to PUR had a greater decrement of
FEV₁ than the controls, whereas the group with
recent low exposure had not. This finding
cannot be explained by concomitant ordinary
welding, as these men actually performed less
ordinary welding during the preceding month,
and also had fewer cumulative days of ordinary
welding, than the pipelayers with ongoing
recent low PUR exposure.

We did not find any evidence of IgE
antibodies in any of the pipelayers, and only
two of them had antibodies of the IgG type.
This is not remarkable, as the prevalence of
specific antibodies may be low in cohorts of
workers exposed to MDI.¹⁷ ¹⁸

The pipelayers were exposed to a complex
mixture of inhaled irritants. We have not tried
to evaluate whether any of the workers
included in the present study have “isocyanate
asthma” in a strict sense. “Variable airflow
limitation causally related to exposure to
non-irritant levels of isocyanates”¹⁹ cannot
ultimately be diagnosed without specific inhala-
tion challenges. Neither questions on the
occurrence and timing of obstructive symp-
toms in relation to work,²⁰ nor specific serum
antibodies,²¹ are sensitive and specific enough
for a strict diagnosis.

In summary, as in other groups of workers,'
exposure to thermal degradation products
from MDI based polyurethane among these
PUR pipelayers was related to adverse effects.
The symptoms and decrease in lung function
cannot be explained by ordinary welding expo-
sure only. We found that four out of five men
who had obtained a clinical diagnosis of
asthma during PUR pipelaying or ordinary
pipelaying work were atopic. However, we did
not find substantial differences in prevalence of
symptom, reported work related symptoms, or
Airway symptoms and lung function from MDI-based polyurethane

lung function between pipelayers with and without atopy. Thus, as has been pointed out before,22 pre-employment removal of atopic workers out of the workforce cannot prevent adverse exposure effects. The only possibility is to minimise the exposure to thermal degradation products by using optimal working procedures.

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