The long-term effects of occupational exposure to vinyl chloride monomer on microcirculation: a cross-sectional study 15 years after retirement

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ABSTRACT

Objectives: To assess residual long-term microcirculation abnormalities by capillaroscopy, 15 years after retiring from occupational exposure to vinyl chloride monomer (VCM).

Design: Cross-sectional study.

Setting: Allier, one of the major areas of polyvinyl chloride production in France.

Participants: We screened 761 (97% men) retired workers exposed to chemical toxics. Exposure to chemicals other than VCM excluded potential participants.

Primary and secondary outcome measures: These participants underwent a medical examination including a capillaroscopy, symptoms of Raynaud and comorbidities, as well as a survey to determine exposure time, direct or indirect contact, type of occupation, smoking status and time after exposure. A double blind analysis of capillaroscopic images was carried out. A control group was matched in age, sex, type of occupation.

Results: 179/761 retired workers were only exposed to VCM at their work, with 21 meeting the inclusion criteria and included. Exposure time was 29.8±1.9 years and time after exposure was 15.9±2.4 years. Retired workers previously exposed to VCM had significantly higher capillaroscopic modifications than the 35 controls: enlarged capillaries (19% vs 0%, p<0.001), dystrophy (28.6% vs 0%, p=0.0012) and augmented length (33% vs 0%, p<0.001). Time exposure was linked (p<0.001) with enlarged capillaries (R²=0.63), dystrophy (R²=0.51) and capillary length (R²=0.36). They also had higher symptoms of Raynaud (19% vs 0%, p=0.007) without correlation with capillaroscopic modifications.

Conclusions: Although VCM exposure was already known to affect microcirculation, our study demonstrates residual long-term abnormalities following an average of 15 years’ retirement, with a time-related exposure response. Symptoms of Raynaud, although statistically associated with exposure, were not related to capillaroscopic modifications; its origin remains to be determined.

INTRODUCTION

Vinyl chloride monomer (VCM) is primarily used in the manufacture of plastics and also serves as a raw material in organic synthesis. VCM is an aliphatic hydrocarbon also known as chloroethene. Its polymerisation leads to a synthetic resin called polyvinyl chloride, commonly abbreviated as PVC. PVC is the third most widely produced plastic, after polyethylene and polypropylene.1 PVC can be made softer and more flexible by the addition of phthalates, and may also replace rubber. Thus, PVC is widely used as follows: pipes and water distribution, a substitute for painted wood (eg, window frames, sills, flooring), electrical cable insulation, inflatable
products, waterproof clothing (eg, coats, skiing equipment, shoes), healthcare products (eg, containers, tubing, catheters), food packaging, dental appliances and vinyl records.1

Harmless in its polymeric form, workers handling the finished PVC product are perfectly safe. In contrast, the at-risk phase lies in the manual descaling of autoclaves used for the polymerisation where workers can come into contact with it during its monomer state.2 Chronic intoxication by the gaseous monomer VCM is linked to several symptoms such as:3 asthenia and dizziness,3 intoxication by the gaseous monomer VCM is linked to hepatocellular carcinoma.8 More generally, VCM abnormalities is capillaroscopy. The widespread identification of these abnormalities as that reported during a VCM exposure,12 our sample calculation indicated that we would need 27 participants in each of the exposed and non-exposed groups to find a change in probability of 95% (ie, 40% in exposed vs 5% in non-exposed) for a power of 80% and a two-sided α of 5%. When we considered an exposed to non-exposed sample ratio of 1:2, 19 and 38 participants, respectively, were needed in the exposed and non-exposed groups. Under the assumption of 0% prevalence in the non-exposed group, sample sizes of 13 exposed and 26 non-exposed were required.

Methods
Participants
We enrolled male retired workers exposed to VCM in PVC production. They provided written informed consent. The study was approved by the human ethics committees from the Clermont-Ferrand University Hospital, France. To be eligible, participants had to be: male (due to the male dominance in this workforce), retired, aged over 60 years, with at least a 5-year occupational exposure to VCM, a time after VCM exposure of at least 5 years, and no exposure to chemicals other than VCM. Moreover, participants with diabetes mellitus were also excluded as it might interfere with microcirculation,16–21 as well as individuals declaring the use or previous use of treatments that might alter microcirculation.

Participants responded to a survey to determine exposure time, direct or indirect contact, type of occupation, time after exposure and smoking history. They underwent a medical examination including a capillaroscopy.
with logistic regression (Nagelkerke R Square). Multivariate models were used to predict the relationship between the capillary parameters and other parameters such as exposure time and time after exposure.

**RESULTS**

**Participants**

We screened 761 (97% men) retired workers exposed to chemical toxics from two leading enterprises involved in PVC production (n=435 and n=91), as well as participants from many subcontracting companies (n=235), also known to have been exposed to VCM. The strict selection criteria of exposure only to VCM reduced the sample size to 21 (figure 1).

Thirty-five age-matched controls were also recruited without occupational or leisure time exposure to chemical toxics.

**Main capillaroscopic outcomes**

There were no missing data. Inter-rater reliability was confirmed with correlations exceeding 0.70 for each parameter. The mean of the values of the two investigators is presented in table 1. Concerning the qualitative data, when a disagreement occurred, the two observers again analysed the data together and requested the opinion of a third expert. The disagreement occurred only for two decreased capillary density <10/mm, and one capillary branching >15%.

Compared with controls, retired workers previously exposed to VCM had higher capillaroscopic abnormalities: enlarged capillaries (0% vs 19%, p<0.001), dystrophy (0% vs 28.6%, p=0.0012; figure 2) and augmented length (0% vs 33%, p<0.001). The mean length was 15% higher in the exposed group than in controls (p=0.020), as well as having a 12% greater diameter of the capillaries (p=0.006; table 1).

**Exposure**

Exposure time was 29.8±1.9 years and time after exposure was 15.9±2.4 years. Time of exposure to VCM was strongly linked with enlarged capillaries (Nagelkerke R Square approximation of 63%, p<0.001), with dystrophy (Nagelkerke R Square approximation of 51%, p<0.001), and modestly linked with capillary length expressed as binary data (Nagelkerke R Square approximation of 36%, p<0.001) or as quantitative data (R²=8%; p=0.031; table 1). Age was not associated with capillaroscopic

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**Figure 1** Participant flow chart.

abnormalities. No multivariate models improved the results from simple regressions.

**Symptoms of Raynaud**
The VCM exposed group also had more symptoms of Raynaud (19% vs 0%, p=0.007) independent of the capillaroscopic modifications (table 1).

**Comorbidities and smoking**
Neither the respiratory nor the cardiovascular diseases were associated with VCM exposure. However, we combined both groups to explore the potential associations between the capillaroscopic parameters and high blood pressure, dyslipidaemia and smoking. Capillary length in the participants medicated for arterial hypertension (n=20/61) did not differ from that in participants without hypertension. Participants treated with lipid lowering drugs with dyslipidaemia (n=10/61) showed a trend for a higher capillary length than participants without dyslipidaemia (p=0.079). Finally, there were no capillaroscopic differences between smokers and non-smokers. However, smokers who had been exposed to VCM tended to have a higher capillary length than non-smokers (p=0.073).

**DISCUSSION**
**Principal findings of the study**
Changes in microcirculation persist for at least 15 years following occupational VCM exposure, with a time-related exposure response. Symptoms of Raynaud, although statistically associated with exposure, were not related to pathological capillaroscopic changes.

**What the study adds**
The microcirculation changes following VCM exposure have been previously shown on 15 workers who ceased their occupational exposure 6 months prior to testing.13

| Table 1 | Characteristics of participants, exposure to VCM and capillaroscopic outcomes |
|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
|                                 | Retired from exposure to VCM (n=21) | Controls (n=40)                  | p Value                         |
| Age (years)                     | 74.4±2.9                           | 76.3±3.2                        | NS                              |
| Type of occupation: blue collar workers, ‘manual’ | 100%                              | 100%                            | NS                              |
| Exposure to VCM                |                                  |                                 |                                 |
| Direct contact with VCM         | 100%                              | 0                               | <0.001                          |
| Exposure time (years)           | 29.8±1.9                          | 0                               | <0.001                          |
| Time after exposure (years)     | 15.9±2.4                          |                                  |                                 |
| Main capillaroscopic outcomes  |                                  |                                 |                                 |
| Density                         |                                  |                                 |                                 |
| Mean density (mm)               | 8.6±0.4                           | 8.8±0.3                         | NS                              |
| Decreased capillary density <10/mm (n (%)) | 9 (43)                          | 16 (46)                         | NS                              |
| Avascular zone <7/mm (n (%))    | 0                                 | 0                               | NS                              |
| Length                          |                                  |                                 |                                 |
| Mean length (μm)                | 291±14                            | 254±9                           | 0.020                           |
| Augmented capillary length >300 μm (n (%)) | 7 (33)                          | 0                               | <0.001                          |
| Diameter                        |                                  |                                 |                                 |
| Mean diameter of capillaries (μm) | 28.9±0.9                         | 25.7±0.6                        | 0.006                           |
| Enlarged capillaries >25 μm (n (%)) | 4 (19)                         | 0                               | 0.007                           |
| Megacapillary >50 μm (n (%))    | 0                                 | 0                               | NS                              |
| Dystrophy                       |                                  |                                 |                                 |
| Capillary branching >15% (n (%)) | 6 (29)                          | 0                               | <0.001                          |
| Haemorrhage (n (%))             | 0                                 | 0                               | NS                              |
| Symptoms of Raynaud             |                                  |                                 |                                 |
| n (%) with Raynaud              | 4 (19)                            | 0                               | 0.007                           |
| Participants with medications which could induce | 2 (9)                      | 4 (11)                         | NS                              |
| Raynaud (n (%))                 | 0                                 | 0                               | NS                              |
| Other causes of Raynaud         |                                  |                                 |                                 |
| Comorbidities                   |                                  |                                 |                                 |
| Respiratory diseases            | 2 (9)                             | 6 (17)                          | NS                              |
| Cardiovascular diseases (except high blood pressure) | 4 (19)                      | 5 (14)                         | NS                              |
| Myocardial infarction           | 3 (14)                            | 3 (9)                           | NS                              |
| Routine medications, n (%) of patients treated for |                                  |                                 |                                 |
| Blood pressure                  | 7 (33)                            | 13 (37)                         | NS                              |
| Lipid lowering                  | 4 (19)                            | 6 (17)                          | NS                              |
| Smoking (n (%))                 | 9 (43)                            | 18 (51)                         | NS                              |

VCM, vinyl chloride monomer.

Our study supports these results over a longer period following VCM exposure—15 years.

The dose responsiveness of VCM exposure and compromised capillarisation is generally, but not always, reported. Although daily VCM doses may have been more informative, the current study was restricted to years of exposure. Thus, we are limited to describing associations with an exposure time—response rather than a dose-response. The number of years of exposure is an easy question for physicians to ask of workers during risk assessment protocols.

The absence of changes in microcirculation on less exposed workers resulted in a suggestion that a threshold of exposure exists. This finding is supported by previous studies showing that long-term exposure (>8 years) induced greater chromosomal aberrations. Further, not all workers exposed to VCM develop microvascular abnormalities, suggestive of an underlying genetic susceptibility (polymorphism of glutathione S-transferase). A finding that female VCM-exposed workers were more susceptible than males to the risk of increased chromosome damage also reinforced the genetic susceptibility theory.

Comparison with other studies

After 50 years of age, minor dystrophies could alter the readability and interpretation of capillaroscopic analyses. Nevertheless, we controlled this parameter by matching the exposed group and the controls on age and we conducted a double-blind analysis by two experienced readers. Moreover, capillaroscopic abnormalities among workers exposed to VCM in the present study were not influenced by age.

VCM has been suspected to cause respiratory and circulatory diseases. However, the similar frequencies of these diseases in both groups do not support this hypothesis.

Diabetes mellitus, high blood pressure, dyslipidaemia or some comorbidities/medications could interfere with microcirculation. Diabetes mellitus was an exclusion criterion and thus could not interfere with our results. Perhaps due to the low numbers of participants, our results failed to support previous findings of compromised microcirculation in participants treated for arterial hypertension. The trend for increased capillary length observed in our participants treated with lipid-lowering drugs could be a response to increased peripheral vascular resistance, in order to maintain their function of metabolic exchange. Similarly, smoking could induce a decrease in tissue perfusion, and dystrophia. We did not observe differences between smokers and non-smokers, with the exception of a trend for abnormal microcirculation among smokers exposed to VCM. The potential of a synergistic effect of tobacco and VCM-exposure warrants further investigations. It should be noted that VCM exposure in the current study was more strongly associated with compromised microcirculation than high blood pressure, dyslipidaemia and smoking.

Previous research into the links between systemic sclerosis and VCM exposure is limited by a single case design and a somewhat dated analyses of a population exposed to solvents. The broader use of a term such as solvents is less specific than the VCM exposure carefully isolated for investigation in the present study.

A higher prevalence of symptoms of Raynaud has been established in workers with VCM exposure, up to one-third of the exposed workers. The comparison between studies with different selection criteria and different sample sizes is difficult. There is also the possibility of selection bias in non-randomised recruitment. Within these limitations, our results support previous data, and extend knowledge by demonstrating that the prevalence of symptoms of Raynaud remained higher at least 15 years following VCM exposure. Furthermore, in the current study, all the participants who suffered from symptoms of Raynaud had never taken medications or suffered from other diseases conducive to Raynaud.

Unanswered questions

Although symptoms of Raynaud are statistically associated with VCM exposure, we could not report a link with capillaroscopic modifications. The pathophysiology of Raynaud’s phenomenon remains unknown. There seems to be primary or secondary vascular failure influenced by a hereditary factor. Decreased perfusion...
pressure could be secondary to systemic hypotension or be caused by proximal arterial occlusion, influenced by many factors; both vascular and intra vascular, neural, environmental or hereditary.\textsuperscript{41} Angiography of the hands of patients exposed to VCM showed occlusions, stenosis and narrowing of the distal arteries with the development of collateral circulation.\textsuperscript{42} Lack of statistical power in our study could contribute to the lack of relationship between the capillaroscopic changes and symptoms of Raynaud.

**Strengths and limitations of the study**

This study presents some major strengths: a rigorous selection criteria of exclusively VCM-exposed participants avoided confounding factors, well-matched controls, a double blind analyses, sufficient number of participants to detect the capillaroscopic differences between groups, the focus on retired workers at least 15 years after the end of occupational VCM exposure. The attendance rate of 30\% (53 of 179 individuals excluded) 15 years after the end of occupational VCM exposure. The pathophysiology of Raynaud after VCM exposure remains unclear. A further limitation may lie in the fact that most of the retired workers exposed to VCM were from the same enterprise; thus, potentially more at-risk manufacturing processes remained undetected. Gender specificity may warrant future studies.

**CONCLUSION**

Although VCM exposure was already known to affect microcirculation, our study demonstrated the potential for residual long-term abnormalities following an average of 15 years’ retirement, with a time exposure response. Symptoms of Raynaud, although statistically associated with exposure, were not associated with capillaroscopic modifications; its origin remains to be determined. Future research could focus on other chemical products that have a similar structure than VCM and more extensive research on the type of occupations at risk of VCM exposure.

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**REFERENCES**

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