Carbon Monoxide and Cyanide Poisoning in Fire Related Deaths in Victoria, Australia


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ABSTRACT

Objective: This study was undertaken to examine the association of hydrogen cyanide and carboxyhaemoglobin in victims of fire related deaths in Australia. The secondary aim was to document demographic data about Australian fire related deaths. Methods: An observational retrospective study was undertaken of autopsy reports from the Victorian Institute of Forensic Medicine. Reports of fire related deaths were electronically searched using the terms burns, “smoke” or “fire” as a cause of death in the calendar years 1992 to 1998. Data on the circumstances of the fire and results of toxicological screening were obtained on 178 persons. Additional whole blood cyanide levels were determined if blood samples were available in storage. Demographics of the victims were analysed, as well as the relationship between carboxyhaemoglobin and whole blood cyanide levels. Results: Most (82%) of the victims died at the scene, whilst 32 victims died after a period of hospitalisation (hours to weeks). Suicide as a result of self-immolation was the reported cause of death in 32 cases. Most of the fires were in houses (114) and cars (29). The blood ethanol level was zero in 112 cases; the remaining cases (53) had a mean level of 0.17%. Other central nervous system (CNS) depressants were recorded in 49 of the 134 cases that received a complete toxicological screen. Carboxyhaemoglobin levels were measured in only 154 of 178 cases. The carboxyhaemoglobin level was zero in 43 cases. The remaining cases (111) had a mean level of 40%; with 44 cases having a level greater than 50%, a level considered to be potentially lethal. Whole blood hydrogen cyanide levels were determined in 154 of 178 cases. The cyanide level was zero in 43 cases. The remaining cases (111) had a mean level of 100 μg/dL; with 44 cases having a level greater than 200 μg/dL, a level considered to be potentially lethal. The results of this study suggest that hydrogen cyanide is a significant contributor to fire related deaths in Australia.
levels were measured in only 138 of 178 cases. The hydrogen cyanide level was zero in 52 cases. The remaining cases (86) had a mean level of 1.65 mg/L; with 11 cases having a level greater than 3.0 mg/L (potentially fatal). Blood ethanol levels were significantly correlated with both carboxyhaemoglobin (R = 0.22, P < 0.01) and cyanide (R = 0.36, P < 0.001). In addition, a significant correlation (r = 0.34) between carboxyhaemoglobin and hydrogen cyanide levels was noted. Conclusions: This study showed a correlation between elevated blood ethanol and whole blood cyanide levels (r = 0.36, p < 0.001) and between elevated carboxyhaemoglobin and hydrogen cyanide levels (r = 0.34). Although the mean cyanide level was 1.3 mg/L (above the level some consider potentially toxic) in those cases with a carboxyhaemoglobin level of greater than 10%, there is insufficient data to permit recommendations for clinical care. Further studies are required on those victims that reach hospital alive.

Key Words: Carbon monoxide; Cyanide; Fire related death; Antidote.

INTRODUCTION

There has been much written in the international literature regarding the contribution of carbon monoxide and cyanide to smoke inhalation injury (1–25). Carboxyhaemoglobin has a specific antidote, oxygen, that is used for all presumed and proven poisonings. Some of the currently available antidotes for hydrogen cyanide present significant problems in clinical use. Before considering specific treatment, the clinician must decide if the victim has clinically significant cyanide poisoning. Techniques for rapid CN analysis have been described but are not routinely or widely available (26,27), so clinical indicators must be used to determine if a patient is poisoned.

Smoke inhalation injury presents the clinician with a unique problem. It is well known that cyanide is a product of combustion of fire in the industrial or domestic setting. However, patients who have been exposed to smoke inhalation injury have multiple potential reasons for being unwell. To date there have been no studies that have been able to provide firm guidelines regarding the management of cyanide poisoning due to smoke inhalation. Limiting factors include data sampling and collection problems. Therefore the contribution of carbon monoxide and cyanide poisoning to morbidity and mortality in smoke inhalation is not known.

There has been no published Australian study on the impact of combined exposure of carbon monoxide and cyanide poisoning on mortality. This paper will attempt to redress this gap in the literature. In order to assess the influence of these 2 poisons in Australian fire related deaths, a retrospective case review study was conducted. Given this methodology in our review of fire related deaths we have made necessary assumptions regarding the role of smoke inhalation in these deaths. In addition to obtaining demographic data about the deaths, the contribution of cyanide poisoning to Australian fire related fatalities was specifically examined. In particular, this study was designed to examine if the carboxyhaemoglobin level or any other factor may be predictive of cyanide poisoning in this setting. The study was also designed to include data on the co-ingestion of prescribed and illicit drugs in fire related fatalities.

METHODS

Victorian law states that all accidental and suicide deaths (including those due to burns and smoke inhalation) must be reported to the Coroner. The Victorian Institute of Forensic Pathology performs the autopsies of all reportable deaths in Melbourne and many of the reportable deaths in rural Victoria. Since 1992, all autopsy reports have been stored electronically. In this study, data was sampled from the database of autopsy reports of the Victorian Institute of Forensic Pathology over the period January 1992 to December 1998.

Data Collection

Using the keyword search terms “burns,” “smoke” or “fire” as a cause of death, the case files of the Victorian Institute of Forensic Pathology were searched. For each case the circumstances of the fire and full autopsy report were examined. The following information was extracted; age and sex of the deceased, approximate time of death and qualitative and quantitative levels of the following substances—carboxyhaemoglobin, cyanide and all other prescribed and non-prescribed drugs.

There were 188 deaths reported in the study period with the cause of death being attributed to burns, fire,
or smoke inhalation. Ten cases were excluded, as there was either no smoke involved (for example, electrocution, hydrochloric acid and hot water) or the death occurred before the fire started (for example, fatal gunshot wound to the head). Thus, 178 deaths were available for analysis.

**Carboxyhaemoglobin and Cyanide Analysis**

At the time of initial autopsy, preliminary toxicological analyses on urine using enzyme multiplied immunoassay (EMIT) for drugs of abuse, and blood using confirmatory high performance liquid chromatography with photodiode array detection (DAD) and capillary gas chromatography (GC-B) and mass spectrometry (MS) for common drugs and poisons were conducted. Other tests, as indicated, were also performed for target substances. Carboxyhaemoglobin was measured by co-oximetry (reported as a percentage of total haemoglobin) and whole blood hydrogen cyanide was analysed by HPLC (reported in milligrams per litre) as per Victorian Institute of Forensic Medicine protocols. Blood was unavailable for sampling in severely burnt bodies and many of the cases that died in hospital did not have suitably stored samples of blood for analysis. A full toxicological screen is now routine on all cases; however before 1995 a screen was only performed at the request of the pathologist. Blood samples are stored in the Toxicology Department of the Victorian Institute of Forensic Medicine at −20 degrees Celsius. In those cases without recorded cyanide levels, sampling of stored blood was performed for the purposes of this study. In total, blood for cyanide analysis was available in 137 of 178 cases (77%). No cyanide antidote treatment is given prior to hospital, and none of the Case Records mentioned any cyanide antidote treatment given in hospital. Hospital Records were not examined. Similarly, no data is available for the length of time of oxygen treatment prior to hospital arrival.

**Statistics**

Data was managed with Microsoft Excel 97 (Microsoft Corporation; USA). All data analyses were performed with SPSS software (SPSS; USA). Comparative data were analysed as independent samples with two-tailed t-tests, statistically significant if P<0.05. Correlations were calculated and one-way anovas were computed.

**RESULTS**

Of the 178 subjects, 114 were males (64%) and 64 females (36%). The age range was from 6 months to 99 years, with a mean age of 42 years. Males comprised the majority of deaths in those aged less than 22 years (36 of 45 cases (80%)). In contrast, females were the majority in those aged over 80 (13 of 20 (65%)). Males had significantly higher blood ethanol levels. Table 1 presents details of the age, sex and blood ethanol levels of the cases. The mean carboxyhaemoglobin and cyanide levels were not significantly different between males and females. The group of very young (<5 yo) and very old (>85 yo) had significantly higher mean levels of carboxyhaemoglobin (43%) than the 5–85 yo aged group (27%).

**Table 2.** Scene of fire.

<table>
<thead>
<tr>
<th>Scene of fire</th>
<th>Number</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>House</td>
<td>114</td>
<td>64.0%</td>
</tr>
<tr>
<td>Car</td>
<td>29</td>
<td>16.3%</td>
</tr>
<tr>
<td>Open area</td>
<td>17</td>
<td>9.6%</td>
</tr>
<tr>
<td>Caravan/Motor home</td>
<td>10</td>
<td>5.6%</td>
</tr>
<tr>
<td>Industrial site</td>
<td>4</td>
<td>2.2%</td>
</tr>
<tr>
<td>Boat</td>
<td>3</td>
<td>1.7%</td>
</tr>
<tr>
<td>Bike</td>
<td>1</td>
<td>0.6%</td>
</tr>
</tbody>
</table>
Table 2 presents details of the scene of the fire for each of the deaths included in this study. Most of the cases were pronounced dead at the scene—146 (82%), while 32 survived to reach hospital alive. 32 of the deceased died as a result of setting themselves alight with the use of an accelerant (self-immolation).

Central Nervous System (CNS) Depressants, Carboxyhaemoglobin and Cyanide

CNS Depressants

Ethanol was the most common central nervous system depressant. Blood ethanol levels were obtained in 165 of 178 cases with a mean ethanol level of 0.056%. Fifty-three (30%) had ethanol detected in the blood and forty-two (25%) of those were intoxicated by medical definition (1) (\( \geq 0.10\% \)). Excluding those aged 18 or less, the mean ethanol level was 0.067% and 30% were intoxicated. Blood ethanol levels were significantly correlated with both carboxyhaemoglobin (R=0.22, \( P<0.01 \)) and cyanide (R=0.36, \( P<0.001 \)). Both the mean carboxyhaemoglobin level and the mean cyanide level were significantly higher in those patients who were intoxicated.

A full toxicology screen was carried out on 134 of 178 (75%) cases. Excluding cases with ethanol and where opiates and benzodiazepines may have been administered by medical personnel after injury, 36 cases (27%) had drugs with central nervous system depressant actions detected in the blood (Table 3). Ethanol was noted to be as frequent a risk factor as other centrally active agents.

Carboxyhaemoglobin Level

Table 4 presents details of carboxyhaemoglobin and cyanide levels in various sub-groups. Carboxyhaemoglobin levels are considered to be toxic in non-anaemic patients at levels greater than 10% (2,3). Carboxyhaemoglobin levels were measured in 154 cases (87%), with a mean level of 29%. Carboxyhaemoglobin was detected in 111 cases (72%) and was above 50% (potentially lethal level (2)) in 44 cases (29%). Of these 44 cases, 33 could be described as dependant (unable to help themselves) by virtue of age (<5 or >80) or ethanol intoxication (blood ethanol level >0.10%). Of those who died of self-immolation, the mean carboxyhaemoglobin level was 9.5%. This is consistent with the previously observed facts regarding self-immolation, whereby the victims frequently die without evidence of inhalation of smoke.

Cyanide Level

Cyanide levels were measured in 137 cases (77%) with a mean level of 1.0 mg/L. Cyanide was detected in 88 cases (62%), with 48 (35%) being above the level previously described as potentially toxic (>1.0 mg/L (15)). Significantly elevated levels (>3.0 mg/L (3)) were recorded in 11 cases. The mean cyanide level of those who reached hospital alive was not significantly different to those who died at the scene. Cyanide levels were significantly correlated with carboxyhaemoglobin (R=0.34, \( P<0.001 \)). The mean cyanide level of the sub-group with carboxyhaemoglobin \( \leq 10\% \) was significantly lower than the sub-group with carboxyhaemoglobin >10% (the level reflecting carbon monoxide toxicity (2,3)), 0.4 mg/L and 1.4 mg/L respectively (\( P<0.001 \)). While the sub-group of self immolation victims may be removed from this analysis, the levels of significance were not altered by excluding the self-immolation group

<table>
<thead>
<tr>
<th>Table 4. Carboxyhaemoglobin and cyanide levels of sub-groups.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Carboxyhaemoglobin</strong></td>
</tr>
<tr>
<td>Environment-open</td>
</tr>
<tr>
<td>-closed</td>
</tr>
<tr>
<td>Died-at scene</td>
</tr>
<tr>
<td>-at hospital</td>
</tr>
<tr>
<td>Ethanol &lt;0.10%</td>
</tr>
<tr>
<td>Ethanol &gt;0.09%</td>
</tr>
</tbody>
</table>

*\( P<0.001 \).
respectively. The clinical significance of whole blood cyanide levels is somewhat controversial, however Baud et al. (15) did demonstrate blood cyanide concentrations were much higher (>5-fold) in fatalities of smoke inhalation than those who survived, indicating that whole blood cyanide levels did correlate with fire related fatality. The effects of combined ‘sub-lethal’ human poisoning is unknown, though rat studies (16,17) demonstrate that combined poisoning of sub-lethal doses of carboxyhaemoglobin and cyanide produces synergistic toxicity. When we grouped out patients by combined levels of carboxyhaemoglobin and whole blood cyanide level with cause of death, we found a definite trend towards a decreased incidence of fatal burns as combined toxic levels increased. Fatal burns were defined as >90% total body surface area burns, or destruction of thorax or skull by fire. Suicides were excluded. We suspect that those who did not die with fatal burns died from secondary causes such as carboxyhaemoglobin or cyanide poisoning. While the validity of this type of subgroup analysis can be rigorously challenged as logistic analysis for control of confounders was not performed, we believe that this crude method of comparing groups is still worthwhile. Table 5 presents the results of this analysis. One third of the group with combined sub-lethal poisoning (an intermediate result compared to those with fatal burns or fatal poisoning) did not have fatal burns. This suggests that, assuming our hypothesis regarding cause of death is valid, in these cases the cause of death may have been the synergistic poisoning of sub-lethal levels of carboxyhaemoglobin and cyanide. A further limitation to this hypothesis is that autopsy reports do not allow one to assume that in the cases with fatal burns the death was due to the burn and the burn did not occur after death. Hence these figures may be an underestimation of synergistic toxicity between carboxyhaemoglobin and cyanide.

### Table 5. Combined toxicity of carboxyhaemoglobin and cyanide.

<table>
<thead>
<tr>
<th>Carboxyhaemoglobin</th>
<th>Number</th>
<th>% with fatal burns</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;10% or Cyanide &lt;1.0 mg/L</td>
<td>52</td>
<td>94</td>
</tr>
<tr>
<td>&lt;50% and &gt;10% and Cyanide &gt;1 mg/L and &lt;3 mg/L</td>
<td>20</td>
<td>65</td>
</tr>
<tr>
<td>&gt;50% or Cyanide &gt;3 mg/L</td>
<td>45</td>
<td>44</td>
</tr>
</tbody>
</table>

**DISCUSSION**

This study was undertaken in order to examine the association of combined carboxyhaemoglobin and cyanide exposure in smoke inhalation fatalities. In an attempt to capture all patients, the search criteria was wide and we are confident that the number of deaths is an accurate reflection of the database. The study was designed to include data on co-ingestion of prescribed and non-prescribed substances. Demographic data was collected. The mean age of the victims was 42 years, which is similar to other published studies (4,8,9). Males accounted for 64% of deaths which is again comparable to other studies (4,9). Australian data on all accidental deaths in the age group 29 days to 14 years is also similar to this study (male proportion 67% (10) vs. 70% in this study). House fires accounted for the majority of deaths.

Males were more likely to be intoxicated at the time of death (78% of the group with blood ethanol >0.10%) and had a significantly higher mean blood ethanol level than females. The intoxicated group had a significantly higher mean carboxyhaemoglobin than the non-intoxicated. The high levels of carboxyhaemoglobin in the intoxicated group were similar in the group of very young and very old. Presumably these two groups have impaired recognition of a fire and impaired escape abilities. One might postulate that they would inhale more smoke than an unimpaired person attempting to escape a fire. This has been noted in other studies (8,9,11).

The international literature contains two large series and two review articles on ethanol levels in burn victims. Marshall SW, et al. (12) reported a series of 190 cases. Ethanol levels were measured in 130 adult cases, and was found to be >0.10% in 69 cases (53%). Squires T and Busuttil A (13) reported a series a 1064 adult cases, in which blood ethanol was measured in 694 cases. A mean ethanol level of 0.14% was recorded, with a level of >0.08% in 393 cases (57%). Howland J and Hingson R (14) discuss 19 studies from 1947 to 1987, reporting that ethanol was detected in 9% to 86% of cases in each series, with levels of >0.10% in the 19 series reported from 37% to 64% of cases. Smith GS, et al. (1) report a meta-analysis of fatal non-traffic injuries involving ethanol of studies published between 1975 and 1995. Their subgroup of burn/fire fatalities (1425 cases) had levels >0.10% in 42% of cases. These papers report higher levels of blood ethanol than does this study. It is unclear why these sample groups have a higher incidence of ethanol intoxication. The prevalence of ethanol in this
study was similar to the prevalence of the other central nervous system depressants recorded in this study.

The incidence of drugs with central nervous system depressant actions is higher than that of a reported series of fatalities (78/534—14.6%) (5), but similar to a reported series of admissions to a burns unit (106/398—26.6%) (6). Clearly it is difficult to quantify the effect of these substances on mortality, as drug levels do not correlate well with clinical effect. None of the drug levels were reported by the Coroner a sign of deliberate overdose.

Carboxyhaemoglobin levels were >10% (potentially toxic level (15)) in 62% of cases. Subgroups with significantly lower carboxyhaemoglobin levels were identified. These included:

1. Those transported to hospital,
2. Self-immolation and
3. Those burnt in an open area.

Significantly higher carboxyhaemoglobin levels were found in the following:

1. The intoxicated,
2. The very young,
3. The very old and
4. Those pronounced dead at the scene.

These observations are readily explained. Those transported to hospital would have had oxygen treatment to lessen carboxyhaemoglobin levels and possibly have suffered a less severe initial toxic dose than the group who were not resuscitated and died at the scene. Similarly, one would expect that the concentration of carboxyhaemoglobin in the air in a closed room would be higher than that in an open environment. Self-immolation often occurs in an open environment and is recognised as a cause of death without evidence of inhalation injury (7). The very young and the very old have impaired escape abilities and thus would be expected to inhale more smoke while attempting to escape.

Whole blood cyanide levels >1.0 mg/L (potentially toxic level (15)) were seen in 35% of cases. Mean cyanide levels were higher and lower in similar subgroups to carboxyhaemoglobin, with the exception that cyanide was not significantly lower in the group that was transported to hospital. Oxygen therapy does not increase the elimination of cyanide. Cyanide levels were significantly correlated with carboxyhaemoglobin levels (R=0.34). Other studies have reported similar correlations (R=0.34 (8), R=0.26 (15), R=0.33 (4)).

There are two other published reports concerning hydrogen cyanide levels in burn or smoke inhalation victims. Baud FJ, et al. (15) report a series with cyanide levels recorded in 43 victims. The mean cyanide level was 2.9 mg/L, with 74% of cases being above 1.0 mg/L. These levels were taken at the scene, however cyanide levels do not decay after death, but may rise up to 0.5 mg/L. It is unclear why this series had much higher levels than we recorded. Perhaps smoke composition is different in French house fires. They also noted that there were many fatalities with sub-lethal levels of carboxyhaemoglobin and cyanide, suggesting synergistic toxicity. Barillo DJ, et al. (4) reported levels in 364 cases (of a total series of 433 fatalities). The mean cyanide level was 1.0 mg/L, with 8.5% above 3.0 mg/L. They also report carboxyhaemoglobin levels in 433 cases, with a mean of 44.9% and potentially fatal levels (>50%) in 195 cases (45%). They also reported an analysis of six other studies involving 613 cases. The mean cyanide level of all cases was 0.98 mg/L. The results of Barillo DJ, et al. and their literature review data (4) are very similar to this study.

In examining predictors of cyanide toxicity it was found that the mean cyanide level of those with a carboxyhaemoglobin of >10% was 1.4 mg/L—a level above that representing toxicity (15). Of all cases with a cyanide level >1.0 mg/L, 96% (46/48 cases) had a carboxyhaemoglobin of >10%. Empiric antidotal treatment of those with a carboxyhaemoglobin level of >10% would result in correctly treating 43 of 83 cases, and exposing the other 40 cases to unnecessary treatment. Currently available antidotes in Australia have life threatening side effects in the non-poisoned patient (dicobalt edetate—Kelocyanor®) or may be unsuitable in those with carboxyhaemoglobin poisoning (Cyanide antidote kit). It has been shown that the mean peak amount of methaemoglobin levels achieved after the administration of 300 mg of sodium nitrite (as found in the Cyanide antidote Kit) is 10.5% (24). This amount is below levels expected to affect significant exposure to carbon monoxide alone. However, in the presence of co-existing carboxyhaemoglobin poisoning and the reduced aerobic metabolism of cyanide toxicity, methaemoglobin represents a potential (as yet undetermined) insult.

This situation results in a dilemma in treating victims of potential smoke inhalation. A treatment with few side effects that can be safely given to non-toxic patients is currently in use in Europe—hydroxocobalamin. There is a paucity of scientific data comparing the efficacy of hydroxocobalamin and dicobalt edetate thus precluding any definitive conclusion about which
antidote is best. However, more is known about the fate of hydroxocobalamin in humans and it’s safety (25). In the emergency situation hydroxocobalamin appears to offer a greater margin of safety. Hydroxocobalamin is recognized as an efficacious, safe, and easily administered cyanide antidote (28,29). Because of its extremely low adverse effect profile, it is ideal for out-of-hospital use in suspected cyanide intoxication. It has been recently recommended as the antidote of choice in the event of a cyanide chemical disaster to prevent needless morbidity and mortality (30). The combination of hydroxocobalamin and thiosulphate has been reported to treat patients with extremely high levels of cyanide poisoning (31) and this combination is to be recommended.

On the basis of these results, a non-toxic cyanide antidote would be indicated in victims of potential smoke inhalation with carboxyhaemoglobin levels above 10%. There was insufficient data to provide meaningful results about the sub-group that were transported to medical care. Clearly this group may have a lesser poisoning that those who die at the scene. Oxygen treatment would be expected to lower any predetermined carboxyhaemoglobin treatment threshold. If a non-toxic treatment were available, then it may be indicated for all smoke inhalation injuries in order to optimise resuscitation and oxygenation, particularly when there is evidence of ethanol use and being rescued from a closed environment. A non-toxic agent may also be of most benefit when administered at the scene.

There are several limitations of this study. Although 178 cases were examined, not all of the cases had complete sets of data. A study with more cases in a series would have more power to detect significant differences, particularly in sub-groups. The study was retrospective and thus some cases may have been missed despite a seemingly thorough electronic search. Approximately 13% of the patients had carboxyhaemoglobin and whole blood cyanide levels measured after arrival to hospital. We did not analyse the time from exposure to death in these patients and the data is not available. Carboxyhaemoglobin elimination is increased with supplemental oxygen, however no data is available on the time or amount of oxygen administered prior to hospitalisation.

Ballantyne, (32) comments that blood samples should be sampled immediately for accurate whole blood cyanide levels, or stored at −20°C for high concentrations, and 4°C for low concentrations. We are unable to describe storage conditions prior to storage at VIFM, therefore, there may be unquantifiable changes in blood cyanide level from time of death until time of analysis.

There is considerable debate about the relevance of whole blood cyanide levels in the setting of cyanide poisoning. We have chosen to use this indicator in our retrospective review of human fire related deaths, because blood levels represent the only objective indication of exposure and potential for toxicity in this group of patients.

Importantly, this study is based on fatalities and this data may not be applicable to patients reaching hospital alive, as they are likely to be a less severely injured group. Further research is required based on those reaching hospital alive.

We used correlation coefficients for establishing the strength of linear association between the outcome and individual exposure variables but did not look at whether the interaction of these variables affected or modulated the relationship. This was partly due to incomplete data.

**CONCLUSIONS**

This is the first Australian study investigating the demographics and carboxyhaemoglobin and whole blood cyanide levels in victims of fire related death. This study demonstrated that many of the victims die with elevated whole blood cyanide levels. Further, cyanide levels are significantly correlated with carboxyhaemoglobin levels. The availability of a non-toxic cyanide antidote would allow safe empiric treatment of victims without putting the non-poisoned at risk. Further research is required to determine the frequency of toxic cyanide levels in those smoke inhalation patients who are transported to hospital. Further research is also required to quantify the synergy between carboxyhaemoglobin and cyanide poisoning by appropriate modelling. The development of more robust biochemical indicators of severity of cyanide poisoning will aide further research in this area.

**CONFLICT OF INTEREST**

Orphan Australia (suppliers of hydroxocobalamin) provided $800 to the Victorian Institute of Forensic Pathology in order to examine 20 stored samples of blood for hydrogen cyanide levels. The company supplied no other assistance. There has been no communication with the company since I supplied the invoice for the cyanide analysis. The company is unaware of the results of the analysis or of the data presentation in August and my subsequent submission of this manuscript.
No conflict of interest exists. Both authors are employed solely by Austin Health.

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REFERENCES

25. Forsyth JC, Mueller PD, Becker CE, Osterloh J, Yeoh and Braitberg


29. Mushett CW, Kelley KL, Boxer GE, Richards JC. Antidotal efficacy of vitamin B12a(hydroxoco-

30. Sauer SW, Keim ME. Hydroxocobalamin: improved public health readiness for cyanide dis-

31. Tassan H, Joyon D, Richard T, Lamaison D, Guelon D, Barakeh S. Potassium cyanide poison-
