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Proof of air embolism after exhumation

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Abstract The detection, storage, and analysis of gas taken from the heart ventricle is necessary to diagnose a fatal air embolism and this requires special precautions during autopsy. When the results of gas analysis correspond to the criteria defined by Pierucci and Gherson [1] the diagnosis "air embolism" is justified. In cases showing putrefaction the diagnostic value of gas analysis was negated [2]. In a series of 15 patients who were assumed to have been killed by air injection in a peripheral vein the corpses were exhumed and a full medico-legal examination was carried out including gas analysis. In 8 cases results could be obtained indicating a mixture of embolised air and gases of putrefaction. In two control groups comprising 10 exhumed bodies and 30 cases showing advanced putrefaction, gas analysis showed putrefaction gases except in 5 cases with gas volumes less than 5 ml in the right ventricle. Therefore gas analysis can be helpful to diagnose fatal air embolism even in cases showing putrefaction while the diagnosis of putrefaction gases only does not exclude this diagnosis.

Key words Venous air embolism · Gas analysis · Criteria for air embolism · Exhumed bodies · Putrefaction

Introduction

The detection of a fatal air embolism requires special precautions during autopsy [2–8] and the investigation should be carried out as early as possible after death [2, 9]. One of the main criteria for the diagnosis of fatal air embolism is the typical gas composition detected by gas analysis; i.e.the gas taken from the heart ventricle should contain less than 15 Vol% CO_2 and more than 70 Vol% N_2, leading to a ratio of both of < 0.1 [1] or < 0.2 [7] and the amount of O_2 should be reduced as compared to atmospheric air (20.9 Vol%). In the opinion of some authors (e.g. Knight [2]) any decomposition of the body negates the diagnosis of air embolism, mainly due to the production of gases of putrefaction.

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Material and methods

In a series of 15 patients (group A; Table 1) who were assumed to have been killed by injecting between 60 and 130 ml of air into peripheral veins, the corpses were exhumed after a time period of 10 to 45 weeks after death. A full medico-legal examination was carried out according to the procedure previously described for cases suspected of air embolism [8]. Gas samples were taken from the right and if present also from the left ventricle and analysed accordingly [8]. Additionally the bodies were examined for injection marks as possible sites of entry; extensive histological and toxicological investigations were carried out and the clinical documents were analysed in each case. In order to better evaluate the analytical results, gas samples taken from control cases where death was due to other causes were analysed accordingly.

The control groups consisted of 10 exhumed corpses (group B) with defined causes of death (Table 2) and 30 cases showing advanced putrefaction (group C) where there was no suspicion of air embolism (Table 3).

Results

The sex ratio and the seasonal distribution of the cases of groups A and B were very similar (Tables 1, 2). The average age and the average time between death and the investigation differed significantly between the two groups (average age: group A, 78 years; group B, 58 years; average burial time: group A, 31 weeks; group B, 19 weeks).

Group A: All patients had been suffering from chronic diseases but in most cases death had occurred suddenly and unexpectedly because the condition of the patients had been stable over a period of days or weeks prior to death. In all 15 cases a possible site of entry of gas into the circu-

Table 1 Cases in group A. Age, sex, month of death (I–XII), time between death and exhumation (PMI) and previous diseases in the 15 cases of fatal air embolism

Case	Age (years)	Sex	Month of death	PMI (weeks)	Previous disease
1	78	Female	V	35	Senile dementia, cardiac insufficiency, pneumonia
2	82	Female	III	48	Senile dementia, cardiac insufficiency, diabetes mellitus, pneumonia
3	80	Female	VII	30	Schizophrenia, cardiac insufficiency
4	82	Female	V	38	Cerebral infarction, hemiparesis, bradycardia
5	80	Male	XI	9	Cerebral infarction, senile dementia, cardiac insufficiency
6	82	Female	VII	26	Cerebrovascular insufficiency, brainstem contusion
7	75	Male	V	33	M. Alzheimer, cardiac infarction
8	63	Male	II	49	Gastric carcinoma
9	92	Female	V	38	Cerebrovascular insufficiency, hypertonia, perpetual arrhythmia
10	74	Male	VI	34	Senile dementia, pneumonia
11	70	Male	I	63	Senile dementia, pneumonia
12	86	Female	X	12	Organic brain syndrome, cerebrovascular insufficiency, pneumonia
13	69	Male	VIII	21	Cerebrovascular insufficiency, cerebral infarction, hypertonia, diabetes mellitus
14	79	Female	XI	11	Cerebrovascular insufficiency, M. Parkinson
15	87	Male	X	15	Myocardial infarction, liver cirrhosis, pneumonia

Table 2 Cases in group B. Age, sex, month of death, time between death and exhumation (PMI) and cause of death of the 10 control cases without signs of air embolism

Case	Age (years)	Sex	Month of death	PMI (weeks)	Cause of death
1	64	Female	XII	15	Lung embolism
2	67	Male	VI	10	Haemorrhagic shock due to intestinal haemorrhage
3	77	Female	VI	16	Acute coronary failure
4	71	Male	VI	17	Acute coronary failure
5	73	Female	VI	38	Cardiac infarction or coronary failure
6	45	Female	VI	9	Lung embolism
7	61	Male	II	34	Cardiac infarction
8	47	Male	IX	6	Acute alcohol intoxication
9	30	Male	IV	21	Rupture of an aortic aneurysm
10	47	Female	X	22	Septicaemia

lation was found. During autopsy and by histology recent injection marks and/or corresponding subcutaneous haematoma were detectable at typical injection sites into veins of the arms. Histologically the typical cell composition of recent haematoma was present in nine cases while in the remaining six a cellular infiltration by leukocytes was found caused by a venous catheter. In serial sections lesions of the venous wall were detectable in 7 cases.

Different volumes of gas were found in the heart ventricles (right ventricle: 5–180 ml, average of 71.2 ml; left ventricle: 2–60 ml, average of 12.5 ml). The analysis of the gas taken from the right ventricle gave results indicating a mixture of embolised air and gases of putrefaction in 8 cases (N_2 > 70 Vol%, CO_2 < 15 Vol%, $CO_2/N_2 < 0.2$; Table 4; Figure 1 - group “exh AE A1”). In the remaining 7 cases the composition of the gases was typical for putrefaction (Figure 1 – group “exh AE A2”). In 6 cases gas was also obtained from the left ventricle. The results of the gas analysis in two of these samples were similar to those of the corresponding right ventricle (cases 7 and 13, Table 3) while in the remaining four cases the composition was clearly different (Table 3).

The full toxicological investigation (acidic and alkaline extractions, analysis by HPTLC, HPLC, GCMS) gave no indication of intoxication.

Group B: In cases 1 and 2 (Table 4) the gas analysis gave results typical of air embolism while in the remaining eight cases a gas composition characteristic for putrefaction was found. It should be noted that in the first two cases recoverable gas volumes were smaller than 5 ml.

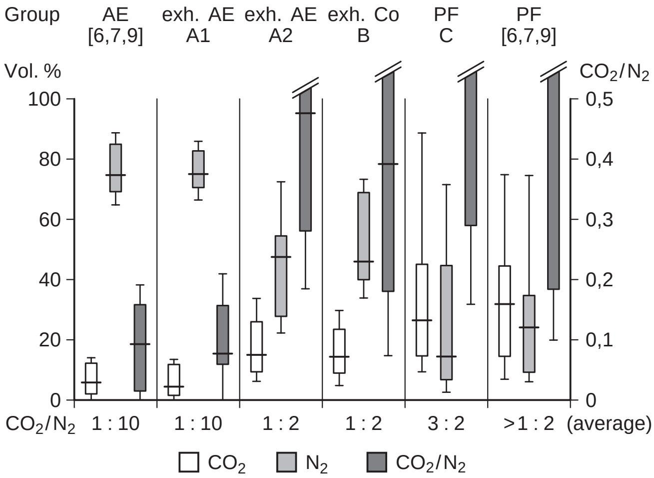

Fig. 1 The results for the three main criteria of gas analysis of the groups are shown in comparison to the data reported in the literature as box-and-whisker plots. The first column gives the relative volumes of CO_2, N_2 and the ratio of both determined in cases of air embolism (AE [6, 7, 9]) by Keil et al. [9], Mallach & Schmidt [6] and Pedal et al. [7] (N = 44).The last column shows results of the same authors in cases of putrefaction (PF [6, 7, 9]; N = 96). In columns 2–5 the results of the groups investigated are demonstrated. The cases of group A were divided depending on the results in cases with values typical for air embolism (column 2: exh. AE A1) and in those showing values typical for putrefaction (column 3: exh. AE A2). The data obtained in group A2 are in accordance with this of group B (exh. Co B) and similar to that of the cases showing advanced putrefaction (column 5: PF C) and also to the data from the literature (PF [6, 7, 9]). The horizontal lines crossing the boxes give the median of the distribution

Group C: In 25 out of 30 cases showing advanced putrefaction gas compositions typical for gases of putrefaction were determined. In the remaining 5 cases the values of the main criteria for the diagnosis of air embolism were close to the defined limits (N_2 > 70 Vol%; CO_2 < 15 Vol%, CO_2/N_2 < 0.2; Tab. 5). A remarkable finding was the high concentration of CO_2 in case 22 (Table 5), where death was due to drowning.

Discussion

Previous investigations have shown that the composition of embolised air (EA) differs from that of atmospheric air (AA; Fig. 2 [2, 4, 10]), because the embolised air is equilibrated with the the gases of the venous blood leading to a concentrations of CO_2 less than 15 Vol% and N_2 greater than 70 Vol% and ratios between both gases of either < 0.1 [4] or < 0.2 [2]. The content of O_2 can vary but concentrations between 8 and 15 Vol% are typical [2]. The production of gases of putrefaction starts some hours after death, at a time when signs of putrefaction are normally not visible [7], leading to an admixture in nearly all cases. If small quantities of CH_4 and H_2 are determined and the other parameters are typical of air embolism, such admixture can be assumed. But the detection of CH_4 and H_2 excludes the diagnosis of "pure" air embolism [7, 9]. In AE it therefore has to be considered that the variation of the gas composition is also due to putrefaction by different types of colonisation. The growth of bacteria in corpses was investigated by many authors beginning in the last century and is extremely variable depending on individual factors [11]. The most common bacteria detected in cadavers are *E. coli*, *staphylococcus* and *pneumococcus*, *clostridium welchii*, *clostridium septicum* and *clostridium aerofoeticum* which are able to produce large amounts of gases (NH_3, H_2S, CH_4, N_2, H_2, CO_2) during putrefaction [11]. Keil et al. [9] have also discussed the production of small amounts of oxygen due to putrefaction.

In cases of "pure" putrefaction the gases can be typically found in the following concentrations: 1–5 Vol% O_2, CO_2 >15 Vol%, N_2 10–70 Vol%, H_2 5–60 Vol% as well as small volumes of CH_4 [1, 6, 7, 9] and sometimes also of H_2S [12].

In our series the total of the different gases varied between 92.6% and 99.9% indicating that the main components of the gas mixture were detected.

In group A the concentration of gases of putrefaction is higher in the right ventricle and the relative volumes of N_2 and O_2 are higher in the left ventricle. These differences indicate that the structures of the atrial and ventricular septum are not altered by putrefaction to the extent that an equilibration could take place. These differences could be due to quantitative and qualitative variations of putrefaction in the pulmonary and the systemic circulation. Since the air-like composition were always associated with small gas volumes artefacts produced by the sampling can be another and more logical explanation (see below).

In 53% of the exhumed cases of group A (cases 1–8; "group A1" Fig. 1) the gas analysis surprisingly gave results typical for air embolism with only small volumes of gases of putrefaction. Different hypotheses have to be discussed as possible explanations:

1. the result may be due to an artificial sampling or analysis;
2. the result may be due to putrefaction producing an atypical gas composition;
3. the gas composition may have been produced post mortem by diffusion of atmospheric air from outside the corpse into the heart;
4. it may be really a mixture of embolised air with only small amounts of gases of putrefaction.

Ad 1 – The equipment used allows the detection of contaminating atmospheric air during the sampling because the aspirometer is filled completely with distilled water and any leak or bypass can easily be recognised by a chain of small air bubbles. But we cannot fully exclude the release of very small air volumes from the equipment that is trapped in the form of bubbles either adhering to glass and tube or in small gaps between connections. This would only be avoidable if the system is filled under vacuum conditions.

– In only 2 out of 40 control cases the results obtained were similar to air embolism (cases 1, 2 of group B). In these cases only very small volumes of gas were recov-

Table 3 Results of gas analysis in the cases of group A (fatal air embolism). The time between death and exhumation (PMI) and the gas volume in the left and right ventricles are given. The relative amounts of N_2, O_2, CH_4, CO_2, H_2 are given for each specimen and the sum of all the components is calculated (Σ). In the right column the ratio of the relative amounts of CO_2/N_2 and of CO_2/O_2 are shown

Case	PMI (weeks)	Gas volume (ml) right ventr. left ventr.	Relative amount of the gases (%)						Ratio	
			N_2	O_2	CH_4	CO_2	H_2	Σ	CO_2/N_2	CO_2/O_2
1	35	58	76.3	20	< 0.1	0.8	< 0.1	97.1	0.010	0.04
		0								
2	48	32	86.8	6.3	< 0.1	5.8	0.9	99.9	0.067	0.92
		2	88.8	9.8	0.1	0.6	0.1	99.4	0.007	0.06
3	31	20	83.0	5.7	< 0.1	5.5	3.4	97.7	0.066	0.96
		0								
4	36	55	74.1	3.0	< 0.1	11.0	7.7	95.9	0.148	3.67
		0								
5	11	36	78.6	1.7	4.3	12.9	0.3	97.8	0.164	7.59
		0								
6	26	42	77.1	2.9	< 0.1	14.4	0.9	95.4	0.187	4.97
		60	76.2	11.9	0.1	8.6	0.9	97.7	0.110	0.72
7	33	5	89.8	4.1	0.4	1.3	< 0.1	95.7	0.014	0.32
		6	91.0	2.3	0.2	2.1	0.1	95.7	0.020	0.91
8	49	5	85.8	2.8	< 0.1	3.5	5.0	97.2	0.040	1.25
		0								
9	38	180	61.3	1.2	5.0	12.4	19.9	95.3	0.202	10.33
		2	77.3	3.7	0.2	1.2	1.0	83.5	0.016	0.32
10	35	98	70.2	3.9	< 0.1	16.3	7.0	97.6	0.230	4.18
		0								
11	64	85	60.6	1.6	< 0.1	29.7	5.0	97.9	0.490	18.56
		0								
12	14	130	54.2	1.2	1.6	18.3	21.6	96.9	0.338	15.25
		5	68.0	2.4	1.1	2.5	1.0	75.0	0.037	1.04
13	22	170	29.9	1.2	6.9	38.8	18.8	95.6	1.300	32.33
		21	35.7	1.4	8.3	34.0	17.6	97.0	0.950	24.29
14	10	102	24.8	0.6	< 0.1	17.7	49.6	92.7	0.714	29.50
		0								
15	15	50	32.5	0.9	7.0	25.7	31.0	97.1	0.791	28.55
		0								

Table 4 The results of gas analysis of the cases of group B (10 exhumed corpses without signs of air embolism). The time between death and exhumation is given. The gas was taken exclusively from the right ventricle. The relative amounts of the gases, the sum of these amounts and the two ratios important for the diagnosis are shown

Case	PMI (weeks)	Gas volume (ml) right ventr.	Relative amount of the gases (%)						Ratio	
			N_2	O_2	CH_4	CO_2	H_2	Σ	CO_2/N_2	CO_2/O_2
1	15	2	69.8	9.8	< 0.1	6.6	11.8	98.1	0.09	0.67
2	10	3	75.9	10.5	0.1	9.2	< 4.3	< 100	0.12	0.88
3	16	26	46.1	4.4	< 0.1	19.9	25.7	96.2	0.43	4.50
4	17	14	38.9	1.0	0.1	17.2	35.1	92.6	0.44	13.2
5	38	35	45.3	7.7	0.2	28.9	< 17.9	< 100	0.64	3.75
6	9	28	54.1	1.5	7.5	35.5	< 1.4	< 100	0.66	23.7
7	34	21	34.4	2.0	< 0.1	22.9	< 40.7	< 100	0.66	11.45
8	6	26	32.1	5.8	< 0.1	22.3	< 39.8	< 100	0.69	3.84
9	21	58	41.9	9.6	< 0.1	34.1	< 14.4	< 100	0.81	14.4
10	22	37	24.6	5.7	< 0.1	41.9	< 27.8	< 100	1.70	7.35

ered (2 ml, 3 ml). In three further cases (cases 28–30, group C) gas analysis gave results near the diagnostic limit (CO_2/O_2 < 0.2) as defined by Pedal et al. [7] but much higher than the ratio as defined by other authors (< 0.1) [1, 9]. More importantly, also here the total gas volume was lower than 5 ml. This would possibly indicate that small volumes escaping putrefaction gas can give rise to the release of air as before mentioned. Very small air

Table 5 The results of gas analysis of the cases of group C (30 control cases showing advanced putrefaction). The gas was taken from the right ventricle only and the relative amounts of the gases, their sum and the two ratios are shown

Case	Relative amount of the gases (%)						Ratio	
	N_2	O_2	CH_4	CO_2	H_2	Σ	CO_2/N_2	CO_2/O_2
1	2.4	0.4	< 0.1	56.2	38.8	97.9	23.40	140.5
2	22.9	0.95	< 0.1	40.2	34.4	98.5	1.75	42.3
3	21.2	0.4	0.2	21.1	50.0	92.9	0.99	52.8
4	4.1	1.1	< 0.1	46.8	45.7	97.8	11.41	42.5
5	2.0	0.4	3.2	50.0	43.7	99.3	25.00	125.0
6	1.1	4.6	< 0.1	43.5	49.2	98.5	39.54	9.5
7	2.3	0.3	< 0.1	38.2	58.6	99.4	16.60	127.3
8	4.6	1.1	< 0.1	46.8	42.3	94.9	10.17	42.5
9	2.4	0.4	< 0.1	55.0	39.8	97.7	22.91	137.5
10	0.9	11.3	2.5	56.3	28.8	99.8	62.55	5.0
11	14.7	0.6	< 0.1	33.0	49.9	98.3	2.24	55.0
12	4.4	0.5	< 0.1	33.1	59.2	97.3	7.52	66.2
13	19.7	2.9	0.2	17.9	56.0	96.7	0.90	6.2
14	5.7	0.6	< 0.1	25.1	63.3	94.8	4.40	41.8
15	17.9	0.9	< 0.1	29.6	47.0	95.5	1.65	32.9
16	18.7	2.5	< 0.1	21.2	47.8	90.3	1.13	8.5
17	24.3	0.7	< 0.1	27.3	44.0	96.4	1.12	39.0
18	24.2	0.7	< 0.1	27.0	41.0	93.0	1.11	38.6
19	23.1	1.0	< 0.1	34.0	40.4	98.6	1.47	34.0
20	22.7	0.9	< 0.1	39.9	34.8	98.4	1.75	44.3
21	45.3	19.2	0.4	28.4	6.7	100.0	0.63	1.5
22	6.4	0.2	0.2	89.9	3.1	99.8	14.04	449.5
23	24.6	5.7	< 0.1	41.9	27.8	100.0	1.70	7.4
24	72.7	1.6	0.4	23.9	1.4	100.0	0.33	14.9
25	68.2	9.9	< 0.1	18.2	0.2	96.6	0.26	1.8
26	76.4	1.6	< 0.1	16.6	4.6	99.3	0.22	10.4
27	69.0	15.3	< 0.1	15.0	0.7	100.0	0.22	0.9
28	69.9	17.3	< 0.1	12.6	0.2	100.0	0.18	0.7
29	78.6	7.7	< 0.1	13.7	< 0.1	100.0	0.18	1.8
30	70.4	18.0	< 0.1	11.6	< 0.1	100.0	0.17	0.6

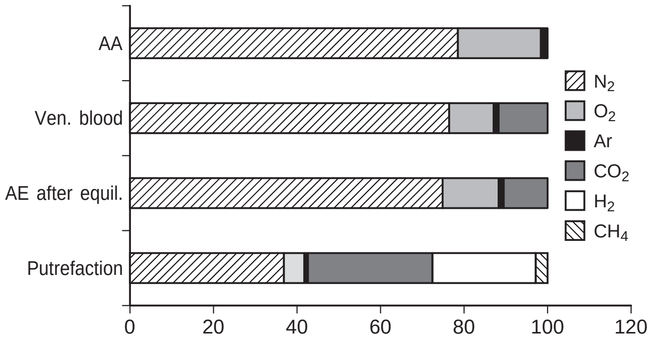

Fig. 2 Schematic representation of the composition of atmospheric air (AA), the physiological gas composition of the venous blood (ven. blood), the gases of the venous blood in cases of air embolism (AE after equil.) and an example for a gas composition in advanced putrefaction

bubbles seem to adhere to the inner surface of the tubes and can give rise to such artefacts [8]. Furthermore the physically dissolved gases could influence the composition of small gas volumes passing throught the water [9]. These observations led us to establish a safety threshold of 10 ml of gas below which any gas volumes recovered should be ignored. If volumes recovered are greater than 10ml this phenomenon can have no significance for the diagnosis.

In contrast, some authors have assumed that "small" gas volumes are indicative of air embolism while "larger" volumes would indicate putrefaction [2, 3, 6]. This could be due to misinterpretation of the same phenomenon because very small volumes of gas will resemble "pure" air rather than larger volumes. But there is no detailed knowledge of the quantity of gas to be recovered if for example 100 ml of air had been injected.

Ad 2 – Since in group A the gas analysis was indicative of air in 53% the corresponding figures of groups B and C would be < 5%. If in addition volumes less than 10 ml are excluded the statistical significance increases: 6 out of 13 cases in group A (46%) and 0 out of 35 cases in groups B and C. There is no hint that putrefaction alone can produce gas composition indicative of air.

Ad 3 – The diffusion of atmospheric air from outside the body into the heart is very unlikely because different gas compositions were usually present in both ventricles. Also, in group A the heart was distended by gas indicating a higher gas pressure inside than outside and the proportion of O_2 was rather low (average of 3.8 Vol%).

In conclusion the results in group A can be considered to be due to air embolism although modifications by putrefaction had occurred. A stepwise strategy was established where cases 1–3 (group A) were considered to be due to this mechanism while in cases 4–6 this diagnosis was given a high probability. Final ascertainment also considered previous history, toxicology and other pathology and histology findings. We therefore conclude that gas analysis can be important to diagnose air embolism even in cases showing advanced putrefaction. This would also be in accordance with other authors [7] although post-mortem intervals as long as in the present series have not yet been reported.

The criteria as defined by Pierucci and Gherson [1] are suitable in advanced putrefaction. The detection of gases of putrefaction alone does not exclude an air embolism. Final evaluation will always have to consider other evidence (typical previous history, typical circumstances of dying [2, 13–17], detection of entrance sites, absence of other causes of death, histological findings [18–20], "matching" confession of a suspect).

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