

collated as a basis for the determination of the clinical significance of leukocytosis in the future.

9. In the diagnosis of malignant disease a leukocytosis is of very subordinate value, and when present is probably not due to the malignant disease, *per se*, but to coexisting chemotactic toxins.

## THE PRESENCE OF AIR IN THE VEINS AS A CAUSE OF DEATH.

By JAMES S. GREENE, M.D.,  
OF DORCHESTER, MASS.

EVER since my graduation thesis was published under the above title<sup>1</sup> in 1864 I have thought that some time I might prepare a supplementary paper. The present article is an attempt to put the thought into execution. While scientists and observers have had their periods of productive activity, it seems to be time for the mere chronicler and commentator to take up his task. In attempting this in supplemental form I shall hope to escape the charge of egotism if in the one paper I sometimes refer to the other and quote a passage here and there.

Forty years ago the subject had been slumbering for a quarter of a century. The preceding period of active interest had culminated in the vote of thanks to Amussat at the close of the discussion which followed the report of Bouillaud<sup>2</sup> to the French Academy of Medicine.

The practical result of this long academic dispute was, as well expressed by Couty, "to make the entrance of air a classical question;" all surgeons knew the danger of certain cervicothoracic venous wounds and the number of cases in operations rapidly diminished. Besides the case of Barlow,<sup>3</sup> omitted from my earliest list, a fatal case was reported by Trélat<sup>4</sup>, and like accidents with recovery are recorded by Armsby,<sup>5</sup> Cheever,<sup>6</sup> Tadlock,<sup>7</sup> and Courvoisier.<sup>8</sup> At the present day surgeons, without ignoring or belittling, have practically eliminated the danger in operations within the recognized danger space. They proceed though they hear the warning sound, but they put on instant pressure at the proximal end of the wound. Of course they avoid the conditions which may invite trouble.<sup>9</sup>

When I wrote a new-found variety of the accident was coming into view, and I aimed at a re-awakening of interest. Cases of death by the entrance of air through the uterine veins were then little known, and there was again, as in the days before Amussat, much skepticism. Years followed, during which general assent prevailed regarding the actual dangers of the accident; and the

acknowledged danger region, already including the uterine veins, had also come to include the sinuses of the dura mater.<sup>10</sup> History still repeats itself. Within the last ten or fifteen years skepticism again has found expression; but while the earlier doubts had their excuse in paucity of recorded facts, the later ones are in some measure due to the overlaying of facts upon facts, with resulting confusion of inference.

In the earlier paper I gathered notes of 11 cases attributed to spontaneous entrance of air into the uterine veins, and 4 cases of forcible injection of air into the uterus. With these were brought into comparison an analogous class "in which gas seems to be developed within the vessels instead of admitted from without." "In fact," I wrote, "there appears to be a regular gradation of instances from such as are physiological to such as are clearly due to the operation of physical laws." After citing instances I added: "It is impossible not to associate this class of cases with that immediately under discussion; and we must admit the possibility of some peculiar and unfrequent condition of the system which predisposes to the reception of the noxious agent or to the more rapid development of fatal effects." And quoting further: "In those cases where gas is unquestionably developed within the vessels it would be useful to investigate its exact composition, and thus determine whether it is generated by decomposition of the blood or merely set free from solution;" added, "the gas might be collected in an inverted beaker and measured approximately, and in a case admitting of doubt whether the gas was atmospheric air or not the rough analysis resorted to by Roux would suffice." Now it is singular and noteworthy that no chemical analyses of gas found in the heart or vessels have since been recorded with one exception to which I shall refer later.

In 1863 Pasteur,<sup>11</sup> then just elected a member of the French Academy of Sciences, received the unanimous award of its *Prix de Concours* for his "memoir upon the organized corpuscles existing in the atmosphere," a memoir which gave the *coup de grace* to the theory of spontaneous generation. From this epoch-making discovery have developed the stupendous and ever-extending achievements of modern bacteriology.

Now let us leap the intervening forty years and ask what is the present attitude of bacteriology toward the venerable subject of Air in the Veins. Professor Welch<sup>12</sup> tells us that to *gas sepsis* "belong most of the cases which have been reported as deaths due to the entrance of air into the uterine veins." "No case of alleged air embolism from the uterus," he says further, "however plausible, can be considered as positively proven without a satisfactory bacteriological examination."

This opinion is founded on the fact that bacillus *aërogenes capsulatus* has been discovered in cases of uterine infection where gas

has been found in the tissues and vessels after death. Dr. Welch states that "the limitation of gas to the right heart and adjacent vessels may occur from invasion of the gas bacillus, and is not, as is often represented, peculiar to air embolism." He does not cite any cases illustrative of this statement, and we may accept the fact on his high authority; but it would, nevertheless, be extremely interesting to read the clinical history and the minute post-mortem conditions found in such a case. It must be conceded, as was regretfully conceded forty years ago, that published cases are often sadly inadequate and inconclusive, and we may sympathize with Dr. Welch in the lament that: "Did we not know how long it takes new knowledge . . . to penetrate throughout the medical world it would be amazing that cases should still continue to be reported . . . of deaths ascribed to air embolism without any bacteriological examination, or even any reference to the possibility of any other explanation."

I cannot forbear to ask, however, if the fervor of the scientist and discoverer has not led him to some overemphasis in statement? I write not from a bacteriological point of view, but, as I have said, only from the historical and clinical viewpoint; but I cannot forget how much the earlier views of bacteriologists have been modified with regard to the virulence of diphtheria bacilli.

The earlier doctrine was that the presence in the throat and nose of the Klebs-Loeffler bacilli was adequate evidence of the presence of the disease in the individual, and of danger of contagion from him; but in April, 1902, a committee of the Massachusetts Association of Boards of Health<sup>13</sup> made a report to that body on Diphtheria Bacilli in Well Persons. I quote from that report this paragraph: "We seem to be justified in concluding, from an examination of the experimental and clinical evidence at hand, that only a small percentage of the morphologically typical diphtheria bacilli found in well persons not recently exposed to the disease are virulent." And again: "They (the virulence tests) bring out the fact that if a healthy person is found to have Klebs-Loeffler bacilli, and there is no connection traceable between that person and cases of diphtheria, the chances are very much in favor of the bacilli being non-virulent."

To-day, according to Solomon,<sup>14</sup> bacteriologists are as far as ever from agreement as to the classification and identification of true and false diphtheria bacilli.

Now may not the bacteriologist hereafter modify his present view regarding the gas bacillus, which is, that its presence in blood-vessels or tissues, even though demonstrated unnumbered days after death, *must* set aside a presumption of air entrance as the cause of death<sup>12</sup> in a case which clinically belongs in that category? And even though he concede nothing, has the bacteriologist the final word? Suppose the pathological chemist should sustain the

obstetrician who makes claim that a given case of sudden death after childbirth is due to the entrance of air into the uterine veins, and should, by analysis of the collected gas, affirm that it was atmospheric air, would not the tables be turned, and would not the burden of proof rest upon the scientist who asserts that the presence of gas bacilli found in tissues after death controverts the theory of air embolism as the cause of death in the case? I believe that bacteriologists know that the gas formed in tissues during life or after death by the agency alike of aërobic and anaërobic bacilli is a compound of hydrogen and carbon dioxide; but I do not think that they have published this knowledge to the world. They also suppose that this gas mixture or compound is a result of fermentation of sugar formed by decomposition of proteids or carbohydrates in the system, or of sugar already present in the blood (in case of diabetics), through the agency of some one or more varieties of gas-producing bacilli.

In the mean time there is the fact recorded by Jürgensen,<sup>49</sup> that Hüfner analyzed the gas collected from abscesses behind sternoclavicular articulation and from the upper part of the thigh, and found nitrogen, 84.45 parts; oxygen, 14.05 parts; carbonic and sulphurous gases, 1.05 parts; but whether the gas was developed in the abscesses or found its way thither from without, both in this case and in that of an analysis by Dressler, there was doubt.

It is nearly ten years since the discovery of the *bacillus aërogenes capsulatus*, the agency of which is invoked to discredit the great mass of evidence accumulated in medical literature showing the danger of air entrance through the uterine veins, and is it "anything less than amazing" that we have to go back to the time of Roux<sup>15</sup> in the early years of the last century to find more than one recorded statement of measurement or analysis of gas found post-mortem in the heart or vessels?

Now let us examine the single observation to which I have alluded. It is not the observation of a bacteriologist. Indeed, it was published when bacteriology was barely emerging from its chrysalis state. Moreover, it is an observation which supports neither the doctrine of the demonstrators of gas sepsis, nor that of the advocates of air embolism, but illustrates that conjectural *terra incognita* or possible middle ground between the territories, equally definite, as I must maintain, of gas sepsis due to bacilli and of air embolism. It seems an instance fairly demonstrated of gas set free from solution in the blood. The case is recorded by M. Hervieux.<sup>16</sup> A young woman was delivered of her second child, a male, after normal labor. On the tenth day a vaginal injection was administered for the correction of fetid lochia. Careful precautions were taken against the admission of air. The eleventh day another injection was given, with the same precautions. This second injection at 7.30 P.M. was followed by the loss of 750 grams of fluid

blood, and by a rigor and chattering of teeth. Later in the evening she had an angry quarrel, ending with an ungovernable nervous crisis. Death half an hour after midnight.

Autopsy was made thirty hours after death. There was no evidence of putrefaction. Cardiac vessels were carefully tied. Heart distended with gas; vena cava the same; contents of latter lost by accidental puncture, but whole inferior cava from right auricle to primary iliacs full of frothy blood. None in iliacs nor utero-ovarian veins, nor superior cava nor its tributaries. Uterus showed no vestige of inflammation nor suppuration. Washing of the interior at fundus revealed the seat of the hemorrhage: two little erosions the size of a pinhead, with small red clots adhering. Appendages perfectly healthy. Gas from heart, chiefly from right cavity, but some from left, collected under water to a volume equalling 40 to 45 grams of water, analyzed with the following result: oxygen, 7 parts; carbonic acid, 11 parts; nitrogen, 82 parts. Same gases as those of air, but in different proportions.

M. Hervieux cites M. Durand-Fardel's case reported at the Academy of Medicine, session of December 9, 1851. A lady aged fifty-six years, of healthy appearance, in coming out of a bath felt oppressed, sank in a chair without power to speak, and died in five minutes. At the autopsy, twenty-two hours after death, the heart was found to be much distended and to contain bubbles of gas, with very frothy blood. The whole abdominal venous system was engorged with dark, frothy blood, and the blood of the splenic and portal veins contained numerous bubbles of gas.

M. Durand-Fardel adopted the view of a spontaneous exhalation of gas during life in the venous system, probably due to an unknown alteration of the blood.

The analogue of these and similar observations is found in the caisson illness. It seems to be determined that symptoms and lesions in that disease are due to the presence in the system of gas withdrawn from solution in the blood.<sup>17</sup>

Hervieux's case was not one which would to-day be claimed as one of air embolism, but rather as an instance of gas sepsis. Its long interval of ten days after delivery, and its interrupted progress toward the fatal issue would remove it from the former category and align it with the latter. The advocates of gas sepsis might claim it as their own but for the counterevidence of the gas analysis.

The puerperal cases on which Professor Welch relies for the support of his contention are all cases of emphysema of uterine walls, and in all but one there was physometra. Such cases develop slowly, either days after delivery or incidentally to the presence in the uterus of a decomposing foetus. They form clinically a class by themselves. The reasonable inference in these cases is that the bacillus *aërogenes capsulatus* found *post-mortem* in the tissues is the fatally noxious agent; but the weak point in the demonstra-

tion is the omission to collect and analyze the gas found in the vessels. When death has occurred suddenly, after hours or days of localized emphysema, the event may well be suspected to be due to distention of the right heart or invasion of the pulmonary capillaries by the gas after long overdistention of neighboring or remoter tissues.

Cases of injury or operation with complications such as gangrene and emphysema are recorded in which slow or sudden death has ensued, and the veins and heart after death have been found to contain frothy blood.

They form a class wherein the presumption now is that the gas found post-mortem is the product of sepsis. Whether the presence of this gas in the heart and pulmonary vessels be the proximate cause of death is a question which should be decided in each instance by the clinical history and the quantity and distribution of the gas.

Many cases of this character were recorded before the discovery of gas bacilli, and attributed by the observer to slow or rapid admission of atmospheric air.<sup>18</sup> Of these only one (referred to by Dr. Porter) is found in surgical history of modern war.<sup>19</sup>

It is curious to note that notwithstanding Baron Larrey's<sup>20</sup> well-known remark concerning the frequency of deaths on the battlefield from entrance of air into the veins, neither the index of the "Surgical History of the War of the Rebellion" nor that of the Chino-Japanese War contain any reference to air embolism.

Parise<sup>21</sup> affirms that the putrid character of the gas developed in some cases of gangrene determines no septic action, but produces death in the same way as does air accidentally entering the veins.

Professor Welch himself admits the "possibility that gas generated by bacteria may have entered wounded veins in sufficient amount and so suddenly as to have caused death."

The surprising thing is that this theory of gas sepsis should be invoked to invalidate a well-established presumption of death by air entrance in a class of cases wholly unlike these septic cases in their clinical aspect, and this without a single supporting verification by gas analysis. On the other hand the clinical picture of spontaneous air entrance through the uterine veins is identical in feature with the same accident occurring in surgical cases and in attempts at abortion. It occurs at the time of delivery or shortly afterward, is sudden, and is seldom lacking in some of the characteristic symptoms.

Take, for instance, the case of Cordwent.<sup>22</sup> A healthy young woman of twenty-eight. Babe and placenta expelled while the patient was standing. Babe fell to the floor, dragging out the placenta. Almost immediately a kind of gurgling sound was heard. Patient remained standing about a minute, holding on to the bedpost, and then exclaimed: "I cannot see; I feel faint; lay me on the bed." This was done, and she died instantly. Autopsy

twenty-four hours after death. Uterus healthy. A portion of wall of fundus about the size of a five-shilling piece, slightly more puffy than the other portions; and on cutting into it air-bubbles escaped. There was no laceration of placental surface. The uterine cavity contained only one small clot; its lining membrane was healthy.

The coronary vein of the stomach was distended by air, and contained only a fine thread of blood. The right side of heart was slightly gorged, and when the auricle was punctured air-bubbles escaped from its contained blood. There can be no mystery about the mechanism of this fatal event. The uterus relaxed after the pain which caused the rapid expulsion of the child, and produced a partial vacuum. The intruding air at the moment when the placenta passed through the vaginal outlet found entrance into the venous system through uterine sinuses not wholly closed by coagula. The inlet was sealed by collapse of the vaginal walls and perhaps by a clot, and the ascent of the imprisoned air to the heart was favored by the erect position of the patient.

Other cases have been reported by Heckford,<sup>23</sup> Davidson,<sup>24</sup> and Braun.<sup>25</sup> Lauffs<sup>26</sup> gathered notes of 18 cases which he classified as cases of spontaneous air embolism through the veins of the uterus. Nine of them I have in this or the earlier paper cited from the original sources. Two others, reported by Draper,<sup>33</sup> occurred in the offices of abortionists, and may have been forced rather than spontaneous, while three, observed in the clinic and polyclinic of Bonn<sup>18</sup> and elaborately reported, were cases of artificial delivery in which it would be difficult to exclude the possible agency of shock or sepsis or both as contributing to the fatal results, though air was found at the autopsy in the right heart and in the large veins in each case. There remain the four following cases to be credited to Lauffs: Levy<sup>27</sup> reported a case of a woman of fifty years who died while undergoing a delivery by forceps. At the autopsy were found partial loosening of the placenta, frothy blood in abdominal veins, air in right internal spermatic vein and in pulmonary vessels. Fürst<sup>28</sup> reported a fatal case occurring in a Vienna hospital. A woman aged twenty-five years, secundipara, who on expulsion of the infant was turned from side to back. Thereupon she immediately became asphyxiated, lost consciousness, and died in an hour after delivery. The autopsy revealed air embolism as the cause of death.

Bischoff<sup>29</sup> gave a case recorded by Hegar. A woman who had experienced a normal labor died suddenly on the fifth day of lying-in. She had laughed loudly while engaged in conversation, and immediately convulsive movements and rattling in throat ushered in death. Autopsy showed frothy blood in right ventricle and right branch of pulmonary artery. Air escaped from veins of the dura. These three cases, while suggestive of nothing so much as spontaneous air embolism, are too meagre of detail to permit of exact

conclusions. The fourth, which I condense in extracting from the paper of Lauffs, is a well-observed case of Kezmarsky<sup>30</sup> occurring at the University Lying-in Clinic of Budapest, March 19, 1877.

An unmarried washerwoman of thirty years was admitted at 10 A.M. in labor at full term of her fourth infant. Hydramnios was diagnosed. From noon the pains, which had been few and weak, became frequent and stronger. About 3 P.M. a bag of membranes emerged, the size of a fist, and during the momentary absence of the midwife from the bedside, burst, flooding the bed with the waters. About fifteen minutes afterward, while the woman was still clearing up the water, the patient suddenly jerked her head backward, gasped painfully for air, her face became livid, and her breathing stopped. The whole scene passed with such lightning quickness that the assistant, Dr. Liebmann, who reached the bed in two minutes, found no pulse, but noticed two incomplete respiratory movements of the thorax, and heard the heart's action faintly as the patient lay on her back. While artificial respiration was undertaken, Dr. Liebmann applied forceps to the child's head in the pelvis, and delivered an asphyxiated male infant of 2780 grams' weight. External pressure caused the expulsion of the placenta directly afterward. In spite of all efforts the heart's action ceased and the patient expired. The liquor amnii amounted to 4 litres. At first glance Dr. Liebmann had the impression that eclampsia might have occurred, but in contradiction of that idea came the decided assurance of the practitioner present and the experienced midwife, that there were no convulsions. The belief was then adopted that either pulmonary embolism or the entrance of air into the veins was the cause of death. Autopsy twenty hours after death by Professor Scheuthauer. The heart was moderately contracted. The left ventricle contained a little fluid blood of yellowish-white color. In the right ventricle, especially near the pulmonary valves, also in the inferior cava and the uterine veins, was pale reddish-brown fluid blood mingled with small and large air-bubbles. Frothy blood flowed from the veins of the uterus when that organ was incised and pressure applied. Professor Scheuthauer thought that the air present was not the product of putrefaction, because the body presented no signs of decomposition, and there was no trace of air found in the jugulars nor the other large vessels.

Kesmarsky remarks concerning this case that the manner of entrance of air was obvious. At the rupture of the membranes the woman was nearly in the Sims position, for she lay on her left side with thighs drawn up, pelvis oblique over the bed, and head on the edge of two flat hair bolsters, so that the face and thorax seemed a little downward. The prominent abdomen was lower than the pelvis, and noticeably lower than the *ostium vaginæ*. The mechanism of the accident was as follows: When the large bag of membranes was suddenly extruded and ruptured, a space was made



between the collapsed membranes and the flabby, voluminous walls of the multiparous vagina. At the same time the intra-abdominal pressure, by the quick escape of a very large quantity of amniotic fluid, became negative, and air rushed in between the membranes and the walls of the uterine cavity. The fetal head descended and the retracting cervix uteri closed around it. The placenta, having become partially detached by the contracting and relaxing uterus, left openings into uterine sinuses through which the air, imprisoned in the uterus, directly entered the veins. All this occurred within the five minutes which elapsed between the bursting of the membranes and the first symptoms of difficult breathing. The absence of external hemorrhage has no value as opposition testimony, because such blood as issued from the placental sinuses was, like the air, prevented from escape by the presence and pressure, as a tampon, of the fetal head.

As though to furnish more links to the chain of proof, surgical cases are not wanting with post-mortem demonstration of fatal air entrance by way of the uterine veins. Wyman<sup>31</sup> and Cheever<sup>6</sup> have each reported a case occurring during aspiration of pelvic tumors. Several instances of sudden death in cases of placenta prævia have been recorded and discussed in German periodicals, and are reasonably ascribed to air embolism. To this category belong cases of Kramer, Kruckenberg, and Heuck.<sup>32</sup> But when in such cases, those for example of Lesse and Zorn,<sup>32</sup> death has been much delayed, the door of controversy is opened as to the possible agency of gas sepsis. The eight cases which I have chosen for citation, added to the eleven collected in my thesis, all lack, it is true, the ultimate proof of the chemical analysis, while some are extremely meagre; but all the reported cases of supposed gas sepsis are likewise unsupported by chemical proof. If the latter class stands on a bacteriological basis, surely the former may claim an equally firm foundation on clinical grounds and convincing analogies.

I suppose that most practitioners of long experience have witnessed cases of sudden death after childbirth, with attendant symptoms indicating the possible entrance of air into the circulation, but have been unable to verify this inference by means of an autopsy.

It is probable that more fatal cases of air entrance through the uterine veins occur than do like accidents in surgical operations, and that present-day obstetricians are less generally cognizant of this danger than surgeons. There would be a correlation between these two facts, if facts they be.

Skeptics have adduced the fact that the accident has not occurred in Cæsarean section. The reply is that since atmospheric pressure does not become negative, conditions promoting the accident are not afforded in that operation. According to Cohnheim, air can find entrance into the veins whenever atmospheric air has access

to the cavity whose tension is less than that of the air. These conditions may be fulfilled in particular cases in a variety of ways:

Veins and sinuses may be emptied by hemorrhage and remain patulous; violent nervous agitations may induce succussion of abdominal walls so as greatly to extend the area of *l'espace dangereuse*; a contracting and relaxing uterus may act as a receiver and pump; or a sudden turning of the body may cause retreat of the viscera, and suction of air through a relaxed and patulous uterus and vagina. Air once introduced may be hindered from escape through the channel of entrance, and the greater veins may easily be the path of least resistance. None of these conditions are presented in the operation of Cæsarean section.

As the controversy stands to-day, in the light of the solitary gas analysis of Hervieux, it would seem reasonable to maintain that no case of assumed death by gas sepsis even with gas bacilli demonstrated could be declared proven, nor any case of assumed death by air embolism could be declared spurious or disproven without collection of the gas found in the heart or vessels, and the demonstration of a pale-blue hydrogen flame on ignition, or an explosion due to the presence of hydrogen or marsh gas.

True, the recorded cases of spontaneous uterine air entrance are rare. So, too, are those of pulmonary embolism after childbirth; and it may be, as has been affirmed, difficult or impossible to distinguish between these two accidents by the symptoms. Pulmonary embolism, however, is usually consequent upon phlebitis and thrombosis of the thigh, and occurs with these concomitants days after delivery, as gas sepsis does with the surroundings of gangrene or decomposition; while spontaneous air embolism, as has been shown, is attendant upon, or follows shortly after, delivery. All these accidents indubitably sometimes occur, and in the interest of scientific truth what is most needed is the urging upon all observers the careful reporting of cases, and the determination in each case of the exact nature of the accident, whenever possible, by post-mortem investigation carried to its last analysis.

The literature of alleged forcible introduction of air into the veins of the uterus has expanded in forty years from the four cases contained in my thesis to a large number.<sup>33</sup>

To the present inquiry these cases have pertinence, first, because, taken as a whole, the cause of death, when confirmed by the finding of air in the right heart and large veins, does not admit of dispute; second, by reason of the striking similarity in symptoms between them and those cases which are chiefly depended upon as characteristic instances of fatal spontaneous air entrance, whether surgical or obstetrical; and it might be added, third, because they offer, especially when the medico-legal element is introduced by a charge of criminality, the best prospect of determining the minimum quantity of air necessary to produce death when admitted into the

veins of the human body. This brings up the third ground of that skepticism to which I alluded to in my opening paragraph, and I shall refer to it later.

Upon the mechanical conditions concerned in the accident, nothing need be added to the remarks already made. Regarding proximate causes it is otherwise, for the period which this résumé is intended to cover is prolific in careful scientific search. It is impossible within the limits here permitted to do more than glance at the conclusions of a few among the noted men who have made patient study of the subject.

In voluminous literature the decade of the 70's, following the revival of professional interest, was surpassed only by the decade of the 30's; in systematic, scientific study and painstaking analysis it surpassed the 30's or any intervening decade, and the impetus thereby given to productive research has extended through the 80's and 90's to the present.

Doubtless both the interest and the results were enhanced by the introduction and the use of instruments of precision unknown to the former generation of workers, and by means of which conclusions could be made much more exact. Panum,<sup>34</sup> in Germany, and Oré,<sup>35</sup> in France, were among the last of the men of note who made contributions to the doctrine of air embolism before the new era opened.

Oré, in 1863, held that air not only distends the right cavities, but also has a sedative action upon the muscular fibre which determines paralysis of the right ventricle, herein taking similar ground to Busse<sup>36</sup> and Marchal (de Calvi).<sup>37</sup>

This chemical theory of Oré, which had some acceptance in France, was contradicted by the studies of Demarquay,<sup>38</sup> who, with his pupil Meric, concluded that air acts only mechanically, herein following the teaching of Magendie.

The theory of Boerhaave and later of Poiseuille,<sup>39</sup> that the lungs are the seat of circulatory obstruction, sustained by Ericsson and Milne-Edwards, was adopted by Claude Bernard<sup>40</sup> in 1873. Muron and Laborde,<sup>41</sup> working together in 1874, maintained the view that brusque injection causes death by distention of the right heart, while injection more slow determines death by suspension of the cerebral functions favored by the diminution of strength of the cardiac contractions. Kowalewsky and Wyssolsky,<sup>42</sup> of Kasan, in 1874, deduced from experiments on cats and dogs a belief in anæmia of the aortic system by the mechanical hindrance of froth in the right heart. Other essayists in the same decade were Pallas<sup>43</sup> and Esleben.<sup>44</sup>

In 1875 a young knight entered the lists to dispute the old doctrines and to establish a new one.

Louis Couty,<sup>45</sup> working in Vulpian's laboratory, made many experiments on animals, together with careful analysis and com-

parison of the labors and theories of all his predecessors in this field, and of all known cases of the accident. On this basis he developed in his thesis for the doctorate in medicine the theory which until recently has held the more general acceptance.

He denied the theories of cardiac paralysis, both chemical and mechanical; likewise the theories that air kills by reaching the brain or by obstructing the lung capillaries. He affirmed, and claimed to have proved, that the entrance of air produces one sole trouble, fall of tension and circulatory arrest; and that all general consecutive accidents, momentary, grave, or mortal, are the direct consequence of this initial circulatory trouble. This stasis of circulation is due not to paralysis of the cardiac walls, for they contract more energetically, but because they contract upon an elastic fluid (air) and compress it instead of propelling it. Further, the distention of the cavities causes tricuspid insufficiency and venous reflux. The blood current into the pulmonary arteries is checked with resulting cerebral anæmia, followed by bulbar death. M. Couty pursued his argument with such eloquence and elaborated it with such wealth of illustration and thoroughness of analysis as to captivate the reader and silence opposition. His doctrine received the seal of Cohnheim's<sup>46</sup> approval, and held undisputed sway for years.

Heart death was the accepted belief of V. Feltz,<sup>47</sup> 1878; Passet,<sup>48</sup> 1886; Jürgensen,<sup>49</sup> 1887. In this country Dr. Nicholas Senn,<sup>50</sup> in 1885, made a monumental study of the subject. He returns to the belief of some of the earlier writers, and espoused by Dr. John Reid, that the conditions producing death are (using Senn's language), "*a*, mechanical overdistention of the right ventricle of the heart and paralysis in diastole; *b*, asphyxia from obstruction to the pulmonary circulation consequent upon embolism of the pulmonary artery."

He believes, further, that "such air embolism is relieved in a comparatively short time provided the contraction of the right ventricle continues unimpaired for a sufficient length of time to force the air through the pulmonary capillaries into the general circulation."

Dr. H. A. Hare, of Philadelphia, in 1889, on the basis of research among the earlier writers and experiments of his own on dogs, avowed his belief in the harmlessness of air entrance into the veins of human beings during surgical procedures. He thought obstetrical cases presented different conditions and might have possibilities of danger.

To give his position its full advantage, I quote the following remark of Dr. Hare, though I have failed to find the paragraphs in his paper devoted to the alleged proof: "We have proved that the quantity of air entering the veins under such circumstances (surgical accidents) cannot be of any great quantity."

Dr. Hare thinks that "there is no evidence whatever that air may not be taken anywhere that blood can flow." But Poiseuille, 1837, is among those earlier authorities with whom Dr. Hare is familiar, and of him Couty remarks: "*Le fait (est) bien prouvé par Poiseuille le sang spumeux necessite pour traverser un reseau capillaire une pression plus forte que du sang pur.*" (Thèse, p. 35.)

Velpeau did not attack the proposition that the entrance of air into the veins had been the cause of fatal accidents, as Dr. Hare supposes, but took the true scientific attitude toward the subject, and by analysis of the reported cases, including one of his own, pointed out those which he classed as doubtful, others as probable, and still others as almost certain, not carrying any doubt to his mind. Had Dr. Hare in this spirit examined the record of some cases since Velpeau's time—Volkman's case, surgery of the head; Trélat's, submaxillary; or Cheever's pelvic case—he must have modified, might have reversed, his opinion.

After these men of the 80's the pendulum of opinion begins to swing away from heart death, though so recently as 1902 we have an American writer, Dr. Malcolm Goodridge,<sup>52</sup> whose research and experiments lead him to the belief that death is due to one of two possible causes:

1. Gaseous distention of right auricle and failure of the blood to reach the left ventricle, and consequently anemia of the brain centres.

2. And to his mind the more important factor, plugging of the coronary vessels with air emboli.

Hauer,<sup>53</sup> in 1890, holds to the theory of lung death, and with him stands the latest investigator, Dr. L. Wolffs,<sup>54</sup> of Berlin, in 1903.

Dr. Wolffs undertook a series of experiments on dogs to determine what becomes of air injected into the circulation, and what is the cause of death; and his conclusions are noteworthy. He finds that the air entering the venous system presses toward the heart. From the heart the pulmonary arteries are filled with air, which passes on into the capillaries. Here its progress meets with a very important resistance. The heart can overcome this resistance if too great a number of capillaries are not too suddenly obstructed. The heart will meet the increased demand the more easily the greater its strength and the less the amount of blood which has been lost.

On account of the peculiar anatomical relations which exist for the lung capillaries, the air is not pressed into the corresponding capillary system, but into the alveoli, where it mixes with the inspired air of the breath. It is not strange that in this process of filtration isolated air-bubbles find their way into the venous capillaries of the lung. This would again be a cause of death through embolizing of vital tracts in the brain, spinal marrow, or coronary arteries, an outcome surely rare, but one that could not be characterized as lung death.

What becomes of the large quantities of air injected, since it does not enter the general circulation nor remain long in the right heart and large veins, except in cases where the whole pulmonary tract is embolized by too large and sudden injections? Even subtracting absorbed oxygen the remaining amount is still far below the injected quantity. This can only be passed out through the lungs. If the explanation be not accepted that embolized pulmonary capillaries are the seat of interruption of the circulation, how could be explained the greater tolerance in cases of interrupted and renewed introduction of air?

Dr. Wolffs has never been able to find air in appreciable quantities beyond the pulmonary capillaries, neither in the left heart nor in the pulmonary veins, and thinks that only an open *foramen ovale* would permit the passage of air into the great circulation after venous injection. Recorded instances of such transmission he believes to be mistakes in observation due either to decomposition, gas formation *in vivo*, or entrance of air during section.

In all this maze of experiment and inference, always incomplete and often contradictory, is there any clue by which to arrive in sight of a goal of final agreement? Perhaps the clue may be got by twisting a thread from Couty with one from Wolffs. Couty was right when he affirmed the stasis of the blood current, not primarily by overdistention and paralysis of the right heart, but by ineffectual contraction upon an elastic medium and venous reflux through tricuspid insufficiency.

While he admitted in obstruction of pulmonary vessels a possible contributing influence making for stasis, he did not assign to this a sufficiently important role because experiment and deduction combined to mislead him into the belief that, since he found little air *post-mortem* in pulmonary arteries after venous injection, therefore little had entered those vessels. Wolffs having shown that air forced into the pulmonary capillaries does not, as Senn thought, enter the general circulation, but escapes into the alveoli, seems to have supplied, if I may stretch the metaphor, the missing link which connects the threads. The clue is stronger by the two threads than by either alone, and guides to a conclusion. Cerebral and bulbar anæmia is the sole physiological cause of the issue in fatal cases of entrance of air into the veins. The mechanical origin of this anæmia is combined lung and heart stasis in proportions varying with the quantity of air introduced and the time occupied in its introduction. The statement must be thus qualified in consequence of the fact, noted by Cohnheim and interpreted by Wolffs, that, to produce lung independently of heart death, more than half the pulmonary capillaries must be obstructed with air emboli, and that this obstruction must be brusque and not gradual. On the other hand, heart death, unaided, would not occur, because the heart must succumb sooner and by a lower degree of distention

in consequence of simultaneous hindrance to blood propulsion from pulmonary air emboli

There can remain to be noted only those rare exceptions to the foregoing statement, fatalities which are neither cases of lung nor heart death, and which can be explained only by the exceptional passage of air into the greater circulation by way of the pulmonary veins.

In my earlier paper I wrote: "The proximate cause of death has been a subject of much controversy, and it has not yet been explained beyond a doubt;" and after giving a summary of the various views of the authorities then known, I added: "The weight of evidence indicates that one of the chief troubles is the impediment offered to the passage of blood through the lungs." It does not seem that forty years have furnished occasion for much change of emphasis here.

The question already alluded to, of the quantity of air necessary to produce death when admitted into the veins of a human being, is an undetermined one, but must not be disregarded.

I know of no recorded case in which the air found *post-mortem* was measured except that which I have reported above, of Hervieux. In his case the air, collected chiefly from the distended right cavities of the heart, but some of it from the left, equalled in volume from 40 to 45 grams of water. This is definite. A woman died, not instantly but somewhat slowly *post-partum*, and a gas chemically resembling atmospheric air, of a volume equalling 35 to 40 c.c., distending the right heart, was the only cause of death discoverable at autopsy. It does not concern us here whether the gas entered the veins spontaneously or was forced in; whether it was a result of sepsis, or was merely liberated from solution in the blood. We need not too carefully inquire why the state of the pulmonary arteries was not reported upon, nor how a small amount of the gas found its way to the left heart. What we are not permitted to doubt is that the heart was stopped in diastole, and that the distended cavities contained 35 to 40 c.c. of gas twenty-two hours after death. If the pulmonary arteries were likewise distended and their capillaries filled with air or gas emboli, while the ascending cava was charged with frothy blood, such facts would increase the estimated total of gas contained in the circulatory organs at death perhaps threefold or fourfold, and would show that the admission of air or evolution of gas was gradual rather than sudden, and that other mechanical and vital factors, besides cardiac paralysis, might have contributed to determine the character of the symptoms and to promote the fatal issue.

Laborde and Muron found that air injected quickly into the veins of animals caused sudden stoppage of the heart, death by cardiac paralysis. Slow injections by small and repeated amounts the animal supported admirably. Neither slow nor quick, but

gradual, brought lung and brain symptoms before the heart stopped beating.

I give below in parallel columns for comparison the conclusions of a few of the later experimenters, American and foreign, respecting the quantity of air which they found capable of killing dogs. These results vary, but as a whole do not differ materially from those of the investigators who were quoted in my thesis:

|   |  |
|---|--|
| ORÉ.  | MURON and LABORDE.   |
| 60 or 80 or 100 c.c., fatal result.   | 100 to 200 c.c., <i>brusque</i> , instant death.   |
| COUTY.  | GOODRIDGE.   |
| 80 c.c., <i>brusque</i> death; 60 c.c. in weakened dog, death.  | 75 c.c. for a dog of forty pounds' weight, usually a fatal amount.   |
| SENN.   | KOWALEWSKY and WYSSOLSKY.  |
| Dogs weighing about thirty pounds would usually recover after an injection of 30 c.c.; double that amount was generally a fatal dose. | 14 c.c. or less at once had killed; 200 c.c. or more in small quantities at a time, borne without disadvantage.  |
| JÜRGENSEN.  | WOLFFS.  |
| Slow injection of small and repeated quantities during sixty-five minutes upon a dog weighing 16 kilos, death after 500 c.c.          | 20 c.c. followed in fifteen minutes by 80 c.c., fatal; 20, 25, and 30 c.c. at intervals covering forty-five minutes, death after 200 c.c. had entered. |

I am ready to admit that the fears I formerly expressed regarding the possible mechanical harm from a leaky hypodermic syringe, or from the ordinary operation of tracheotomy, were exaggerated. I do not believe that a bubble of air introduced into a vein is likely to cause alarming symptoms. What may be the minimum quantity capable of doing this in an enfeebled, perhaps exsanguinated, possibly frightened or agitated subject cannot now be affirmed.

Conjectures derived from algebraic formulæ founded on weight and volume comparison in experiments on animals must be delusive.

A statement of Couty is illuminating. After remarking the evidence of cerebral anæmia in animals as only manifest in hurried respiration in the series of observations (the second of his four) illustrating the slightest manifestation of general, and not merely local, trouble, he says: "With man, whose brain is more sensitive, this circulatory trouble, this momentary fall of tension, suffices to produce a *syncope*, a *momentary loss of consciousness*." (Italics are Couty's.)

And again he says, after noting the comparative tolerance of some animals: "These accidents are much more rapid with man in whom the heart, we have seen, is more dilatable, in whom the organs are much more dependent, and the brain more susceptible. But even in this more complex organism after the entrance of air the arrest of the central co-ordinators, heart and brain, is not instantaneous; convulsions when they have occurred have super-



vened an appreciable time after the hissing sound—that is to say, twenty or thirty seconds.”

The physician cannot overlook the lesson of the larger therapeusis which is constantly enforcing attention to the practical truth that the delicate, nervous equilibrium and the sensitive brain, which accompany the more complex development of the human being, constantly have to be heeded in practice, and must necessarily detach man from comparison with animals, even the superior ones, when there is question of anything in the nature of depressing influence or shock.

It remains but to consider briefly the therapeutics of the subject.

Couty advocated two measures, the one mechanical—bleeding; the other chemical—inhalation of oxygen.

Senn urges, besides indirect treatment by venesection and cardiac stimulants, direct treatment by (a) puncture and aspiration of the right ventricle; (b) catheterization and aspiration of the right auricle.

These measures he believes to be justified by experimentation as a last resort in all cases where the indirect treatment has proved inadequate to meet the urgent indications. Lauffs, two years later, also suggests puncture of the right ventricle.

Goodridge's experiments were undertaken to determine the therapeutic value of aspiration of the right ventricle, according to the proposal of Senn, combined with venous transfusion of normal salt solution. He concluded that good results may be expected from the combined method of treatment.

The radical direct measures proposed, however well founded in theory and well supported by experiment, are as yet untried in any case of the accident in man.

On the obstetrical side suggestions for treatment are meagre. Some of the more recent books on obstetrics ignore the whole subject; others touch it doubtingly. One of the latest gives reasonable space, but has no word on treatment.

The following remarks are found in the *American Text-book of Obstetrics*: “Very little can be done for the patient even when assistance is close at hand. The cervix should be cleared of clots. Artificial respiration and hypodermic administration of stimulants should be promptly employed. Tracheotomy and the inhalation of oxygen gas, in order to inflate the lungs and to expel the air emboli, have been suggested.”

If this utterance be accepted as the concise expression of present-day expert opinion in obstetrics, it follows that the emphasis must be upon preventive measures. These consist wholly in carefully guarding against the risks which recorded experience and tested theory have signalized. It means watchfulness to avoid any conditions which may produce, ever so transiently, a negative atmospheric pressure within the abdomen at the time of expulsion of the contents of the uterus, and for a brief but undetermined period

following. Especially is there need of this if the delivery be rapid, if it be attended or preceded by considerable hemorrhage, if there be placenta prævia, or any need of operative procedures. Care should be taken to follow down the contracting *fundus uteri* with the hand, and maintain manual pressure until continuous tonic contraction is established; to be prudent and conservative in dealing with the third stage, whether delayed or not; to guard the patient against dangerous positions at the time of delivery, and against dangerous change of position or agitation afterward; in a word, and adopting the phrase of M. Hervieux, to "conform rigorously to all the precepts of the art."

I draw the following conclusions: The question being on the occurrence of fatal accidents from spontaneous entrance of air into the veins, those who take the affirmative can accept the burden of proof and urge the paramount importance, in every disputed case, of the *earliest possible* measurements and analysis of the gaseous contents of the veins and heart. This is what the opponents of the proposition have failed to do or even to suggest. Experimental work should also be directed to declare the mechanism of air access to the heart by the channels of the remoter vessels, whether they be the sinuses of the dura mater or the sinuses of the parturient uterus.

These are the problems which claim elucidation, to the end that the theory of accidental fatal air embolism be no longer dependent on testimony however strong, nor on analogy however convincing, but be established on an indisputable basis of demonstration.

#### BIBLIOGRAPHY.

1. Greene. THE AMERICAN JOURNAL OF THE MEDICAL SCIENCES, January, 1864.
2. Bouilland. Bulletin de l'Académie, vols. i. and ii.
3. Barlow. Medico-Chirurgical Transactions, vol. xv. p. 29.
4. Trélat. Société chirurgicale, Paris; The Lancet, March 30, 1872.
5. Armsby. Boston Medical and Surgical Journal, February 4, 1864, vol. lxx. p. 11.
6. Cheever. Ibid., February, 1868, n. s., vol. i. p. 24, and November 29, 1883.
7. Tadlock. THE AMERICAN JOURNAL OF THE MEDICAL SCIENCES, 1875, p. 280.
8. Courvoisier. Correspondenzblatt f. Schweizer-Aerzte, 1880, p. 205.
9. J. Collins Warren. Discussion of Senn's paper. Op. cit., 1885.
10. Volkman. Verhandlungen d. Deutschen Gesellschaft f. Chirurgie, Bd. vi. p. 32; Bergmann, *ibid.*, 1877, p. 366; E. Meyer, Arch. f. Ohrenheilkunde, Bd. xlix. p. 241; Tillmanns, Berliner klinische Wochenschrift, January 17, 1881.
11. La Vie de Pasteur, Paris, 1903.
12. Welch. The Shattuck Lecture of 1900, pp. 290-292, Transactions of the Massachusetts Medical Society.
13. Journal of the Massachusetts Association of Boards of Health, July, 1902.
14. Solomon. THE AMERICAN JOURNAL OF THE MEDICAL SCIENCES, January, 1904, p. 107.
15. Amussat. Recherches sur l'introduction accidentelle de l'air dans les veines.
16. Hervieux. Maladies puerperales, 1885, pp. 1889-1900.
17. Bouchard. Pathogenie des hemorrhages, Paris, 1869; E. Cassert, Bordeaux, 1886-1889.
18. Bert, De l'influence des modifications dans la pression atmospherique; Gabarret, Dict. Encyclopedique, I., tome vii. p. 155; Hill and McLeod, Caisson Illness or Divers' Palsy, an Experimental Study, Journal of Hygiene, October, 1903, vol. iii.; also Couty, Thèse, p. 129.
19. Garden. Indian Medical Gazette, June, 1881; Osterloh (two cases), Berichte und Studien aus dem Königl. Sächs. Entbindungs-Institute in Dresden, 1874-1875, Bd. ii. p. 79; Bruler (two cases), Chicago Medical Journal, March, 1858; Wachter (two cases), Inaug. Dissertation.

München, 1875; Loevy, Inaug. Dissertation, Berlin, 1880; Klinik und Polyklinik, Bonn (three cases); Porter, Journal of the American Medical Association, November 15, 1884; Nancrede, Discussion of Senn's paper, op. cit., 1885.

19. Medical and Surgical History of the British Army in the Crimea and Turkey, vol. ii. p. 277.

20. Larrey. Cliniques Chirurgicales, and Sir Charles Bell's Practical Essays.

21. Parise. Archives de méd., November, 1880.

22. Cordwent. St. George's Hospital Reports, 1871-1872, vol. vi.

23. Heckford. Medical Times and Gazette, 1867, vol. i. p. 137.

24. Davidson. The Lancet, June 9, 1883.

25. Braun. Wiener med. Wochenschrift, 1883, Bd. xxxiii.

26. Lauffs. Inaug. Dissertation, Bonn, 1887.

27. Levy. Hosp. Medeleisen, 1853, Bd. vi.

28. Fürst. Centralb. f. Gynäkol., 1883, No. 39, Ber. v. Menzel.

29. Bischoff. Arch. f. Gynäkol., Bd. v. p. 179.

30. Kezmarsky. Ibid., 1878, Bd. xiii. p. 200.

31. Wyman, H. C. North Michigan Medical Society Transactions, Lansing, 1877-1880, vol. vii. p. 398.

32. Lesse. Zeitschr. f. Geburtsch. und Gynäkol., 1896, Bd. xxxv. p. 185; Heuck, *ibid.*, 1894, Bd. xxviii. p. 140; Kruckenberg. Centralb. f. Gynäkol., 1894, No. 20; Hubl, Wien. klin. Wochenschrift, 1900, Bd. xiii. No. 5, p. 111; Kramer, Zeitschrift f. Gynäkol. und Geburtsch., 1887, Bd. xiv. p. 489; Zorn, Münchener med. Wochenschrift, 1898, No. 18; Boss, J. D., Ueber placenta prævia, Breslau, 1894.

33. Landsberg. Zeitschrift Geb-Kunde, 1842, 13 d. 12; De Paul, The Lancet, July 21, 1860, Gaz. des hôpitaux, 1860, No. 91; Wynn Williams, The Lancet, No. 10, vol. i. p. 288 (not fatal); Olshausen. Monatsschrift f. Geburtskunde, January, 1865; Marburg, Berliner klin. Wochenschrift, 1878, No. 23 (not fatal); Litzman, see Lauffs and Arch. f. Gynäkol., 1871, Bd. ii. p. 176; Winkel, *ibid.*, 1876, Bd. x.; Stande, Zeitschrift f. Geburtsch. u. Gynäkol., 1878, Bd. iii. p. 190; Herdegen, Centralb. f. Gynäkol., 1878 (two cases); Mangiagalli, Cent. f. Geb., 1880, No. 19, from Annali di Ostetricia, January, 1880; Porter, op. cit., ref. No. 18; Draper, Boston Medical and Surgical Journal, 1883; Seymour, American Journal of Obstetrics, April 1884, p. 352; Gordon, Discussion of Senn's paper, op. cit., 1885; Borg, C., see Lauffs, op. cit., ref. No. 25; Spiegelberg, see Kezmarsky, op. cit., No. 29; Scanzoni, *ibid.*; Hektoen, North American Practitioner, March, 1891, p. 99; Palmer, W. H. (two cases), ref. lost.

34. Panum. Experimentelle Beiträge zur Lehre von der Embolie, Virchow's Archiv, 1862, Bd. xxv.

35. Oré. Gaz. hebdomadaire de méd. et de chir., ix., No. 3, January, 16, 1863, Paris, and Étude historique et physiologique, Paris.

36. Busse. Lettre à la Gazette médicale, 1839.

37. Marchal (de Calvi). Annales de la chirurgie Française et étrangère, 1842.

38. Demarquay. Essai de pneumatologie médicale, 1866.

39. Poissenille. Lettre sur les causes, etc., Gaz. médicale, 1866.

40. Cl. Bernard. Société de biologie, Paris, Fev. 8, 1873.

41. Muron and Laborde. *Ibid.*, 1874.

42. Kowalewsky and Wyssolsky. Pflüger's Archiv, vol. viii., parts xi. and xii., from London Medical Record, April 29, 1874.

43. Pallas. Essai sur l'introduction de l'air dans les veines, Mém. et bull. Soc. méd. et chir. de Bordeaux, 1872, pp. 544-551.

44. Esleben. Plötzlicher Tod in Folge von Luftintritt in die Uterin Venen, 1876.

45. Louis Couty. Thèse, Étude exper. sur l'entrée de l'air dans les veines, Paris, 1875.

46. Cohnheim. Vorlesungen über allgem. Pathologie, Berlin, 1877.

47. V. Feltz. Expériences démontrant le rôle de l'air, etc., Paris, 1878.

48. Passet. Ueber Luftintritt in die Venen, Arbeiten a. d. Pathol. Inst. zu München, 1886, S. 293 ff.

49. Jürgensen. Luftintritt in die Venen, Deutsches Archiv f. klin. Med., Bd. xxxi. p. 441. Luft im Blute, Deutsches Archiv f. klin. Med., 1887, Bd. xli. p. 569.

50. Senn, N. Transactions of the American Surgical Association, 1885, vol. iii.

51. Hare, H. A. Therapeutic Gazette, 1889, third series; also, THE AMERICAN JOURNAL OF THE MEDICAL SCIENCES, November, 1902.

52. Goodridge, Malcolm. THE AMERICAN JOURNAL OF THE MEDICAL SCIENCES, September, 1902, p. 461; and *ibid.*, March, 1903, p. 519.

53. Hauer. Erscheinungen im grossen und kleinen Kreislaufe bei Luftembolie, Zeitsch. f. Heilkunde, 1890, Bd. xx. p. 159.

54. Wolffs. Virchow's Archiv, 1903, Bd. clxxiv. H. 3.