— Foreword —
Some Reflections on the Man Behind the Machines

From its origins in applying bellows to resuscitate drowning victims in the 1760s, the field of mechanical ventilation has advanced because clinical needs have been identified and then met by clever inventors and engineers, whose technical and engineering expertise engendered new and better machines. No exception to this pattern, the history of modern mechanical ventilation has been shaped by several creative innovators whose names are emblazoned on the equipment we commonly use today, for example, Bennett, Bird, Engstrom, and Emerson.

The field lost one of these innovators this past year—John Haven "Jack" Emerson—and it seems fitting for RESPIRATORY CARE to commemorate his career by publishing his own reflections on the contributions he made to the fields of mechanical ventilation and to respiratory care. The accompanying article is a transcript of a lecture that Emerson delivered to the Massachusetts General Hospital Department of Anesthesia Critical Care group in 1985. At that time, we invited Mr Emerson to address this group regarding these reflections.

A few words of explanation are needed for the reader. First, this lecture was invited as an informal seminar, accompanied by a few of Emerson's selected slides (some of which are reproduced as figures). The article is a transcript of a lecture and therefore reflects the folksy spontaneity of conversation rather than the polish of a chapter-ready manuscript. Indeed, the editors have purposely avoided rigorous editing in order to preserve the folksy affability that was an endearing trait of Jack Emerson.

Also, Mr Emerson names specific persons in his lecture and we have done our best to transcribe the names accurately, while recognizing that the 13-year-old recording leaves room for errors in this regard. Most of the names of the questioners could not be deciphered.

Finally, I would like to add a personal introductory note. As a Fellow in Critical Care at the Massachusetts General Hospital then, I had the privilege of inviting and introducing Jack Emerson. I distinctly remember the self-effacing enthusiasm with which he agreed to deliver the lecture. My experience of inviting and hearing the lecture was framed by two main feelings: first, awe at meeting the man behind the machines that we used daily in our intensive care units then and second, reverence for the sense of craftsmanship that Jack Emerson exuded as he described a career of building sturdy, practical, life-saving machines. Overall, I believe that this article will pay tribute to Jack Emerson by putting his own words before the readership of RESPIRATORY CARE and, in so doing, celebrate thoughtful innovation and craftsmanship—values that will surely enhance our own practices of respiratory care.

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Some Reflections on Iron Lungs and Other Inventions

John H Emerson

Transcribed from the videotaped lecture given by Mr Emerson during a meeting of the Department of Anesthesia Critical Care at Massachusetts General Hospital in 1985.

Thank you very much for asking me. I hope I can tell you some things you'll be interested in. Now, particularly, I gather you'd like to know how our ventilator came about. If I put these slides through, I might put them through right in the beginning, quickly—just so you can see how I got started.

I was from New York, and I didn't do very well in school at all. I never graduated from high school. My family sent me up here, because everybody went to Harvard or Radcliffe. That was traditional in my family. In fact, my father told me if I didn't go, I'd be the first Emerson since they landed on the shores of Ipswich—but that's me! My brother, who was in plant physiology at Harvard, got me a job in the physics lab. I swept floors and learned how to oil lathes and machine stuff.

Then next year I got a job at the medical school trying to make very, very fine fibers for a cousin of mine, Alexander Forbes, for a string galvanometer. He was trying to make one-centimeter-long fibers, gold plated, of quartz for a galvanometer, a special galvanometer he was having made, studying nerve action currents, which they were not able to study in those days, because the galvanometers wouldn't respond fast enough. So, if you had it short and small, and they wanted a half a μ—you know how big that is—you look at a spider web, and then you reduce it. You could hardly see these darned things! And I found a way to make them for him. Took me about a year, and they used to blow quartz in a room that was all covered with felt, and they'd pick them up off the wall, these little things. I had a bunch of things that spun around like that, and I wound them up.

Anyway, I decided then that, well, my brother being a plant physiologist, studied chlorophyll—what do they call it?—photosynthesis was his specialty, and he was trying to get pure cultures, and I developed a micromanipulator for him to get pure cultures, which is still on the market. In fact, there was a guy came to my shop very recently. He'd gone all over Europe, went to Zeiss and Leitz and came back here and somebody said, why don't you come over to our place? And he bought the manipulator that I had made for my brother. It's different in that instead of having things that go that way and that way, to move that way and that way, I had a lever like an airplane control—no matter which way you moved the handle, it moved the needle that you were controlling, very little, in the opposite direction. It reversed it, so under a microscope, it was erected. This has been a useful instrument for people. In fact, talking about nerve action currents, it was used, a bunch of them together, at Boston University, way back then for tracing the fibers out of a cat's brain to find out what controlled what. See, that's the kind of thing they were doing in those days, and they used my manipulator.

Anyway, let's go quickly through this, and then I'll tell you. There's the oxygen tent I told you about, which I made for James Wilson. He was a resident at Children's Hospital. Let's see now, it was probably '29 or so that I made that. He had a milk pail that he bought at Sears Roebuck. There was a brand new Sears Roebuck store, that one that's over there. He used the milk pail and put a motor under it. The trouble was that—you put ice in that thing—and the motor was underneath to circulate the air to the tent. Only trouble was they were made of 'tinned' steel and in a very short time the salt and ice rusted the steel tank out that dripped on the motor, and it wasn't a good arrangement. So, we made one out of copper for him, and he wanted something that wasn't as cumbersome as Barach's tent for pediatrics.

OK, let's just go quickly. All right, here's the iron lung. Now, the same Jim Wilson, (I've just got to go a little into how I got into this) Jim Wilson then asked me if I had any ideas on how to improve the Drinker respirator (Fig. 1). That was a new thing, and they were selling them for around $3,600. It was a rectangular tank affair with thick walls, because they were flat walls. They had valves, a motor to drive valves, and a blower to change the pressures. So that it made an awful lot of noise.

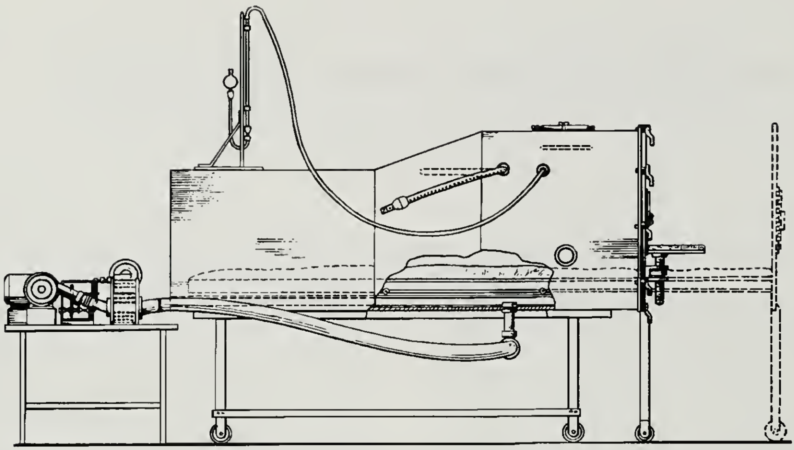

Fig. 1. The first "iron lung" to receive widespread use was developed in 1928 in Boston, and was patented by Philip Drinker and Dr Louis Agassiz Shaw. It was cumbersome and inconvenient but saved a number of lives. It had a sliding bed with head-wall attached, and a rubber collar. Pressure changes were created by a rotary blower and an alternating valve. During a polio epidemic the Consolidated Gas Company of New York paid for building large numbers of these respirators, and reports of their use spread quickly around the world. Reprinted, with permission of JH Emerson Co.

I told him I thought that a simple diaphragm would be better. I made a box that size, which I took to Children's Hospital recently to show them. I still have the box—a very simple thing with a big piece of leather [from] a car seat that I got from my junkyard. That's still in good condition, incidentally. You push the handle up and down and it would change the pressure in the box. Well, I took this thing over to Children's, and I gave it to Jim Wilson, and he said, "Could I keep it and take it to Drinker?" And Drinker said, "That won't work. We thought of that." And so they gave it back to me.

Well, I talked to my father about this ... (this was in '30-'31), and about maybe a month after, I got a short letter from my father. Now my father was the head of public health at Columbia. He simply said (he was an epidemiologist) and he said, "We're heading for a bad epidemic of polio this year. If you're ever going to try that idea of yours, now's the time to do it."

Well, the epidemic came pretty fast and so I went across the river here [to] Robertson Boiler Works, and I said (I had no drawings, absolutely nothing), I just went into that place and said, "Oh, make me a round tank about so big, well, 28 inches, maybe, in diameter, and put some legs on it. We'll take it from there." After I picked that tank up, in two weeks we had this thing completed (Fig. 2). That machine, I got into it and got a bad cold (I mean a sore throat) from one night. It worked, you see! I took [the tank] down and showed it for my father at Willard Parker and one other hospital, and he told me to stop at Rhode Island on the way back, at their contagious hospital. I put it in there late in the afternoon and they told me, "Well, we have a patient. We have no machines." They had four Drinkers in use. You couldn't hear yourself think in the place it was so noisy. [The patient] was a young priest. They said, "He'll die at night. We have no way to ... we have no place to ... " We tried—so, we put the patient in—it worked perfectly. It ran for six months. The patient lived, and we decided we'd try and make iron lungs.

I asked the Boiler Works to make five more tanks. News got around here in Boston that I was doing this. And I decided that I would try to show it at the American Hospital show, which was coming up in Toronto. So, I had a call from Drinker. No! He came into my shop and told me if I tried to make this iron lung he'd put me out of business. He had patents coming up. Well, in those days, you know, doctors didn't patent things much (and especially life-saving things). It made us mad, anyway, to be threatened like that. But we went ahead and completed the machine and took the second machine to Toronto. We got it completed two days before the meeting, spent one day—no we started in the night, driving to Toronto with that iron lung across the back seat of a Dodge Touring car with the top down. As we went through Albany, it stuck out so far that my co-helper, Mr Garrison, was driving and the headrest knocked over some of these street signs.

We made it to Toronto. We set up this booth. The Drinker respirator was there. We were offering [ours] at $1,000. All I can say is at the end of that meeting, everybody knew that I had the machine that was going to be used! This hospital

Fig. 2. Because of a severe poliomyelitis epidemic in 1931 John Haven Emerson of Cambridge, U.S.A., built a simplified respirator. It cost less than half as much as others, but contained many improvements. It operated quietly, using a bellows to create the changes of pressure (as Woillez's did, but with a motor added). A wide range of speeds was instantly available. Opening and closing were rapid and convenient. It could be pumped by hand if electricity failed. The first Emerson "iron lung" is now preserved in a glass case in the United States National Museum (the Smithsonian Institution) as the prototype of respirators constructed since 1931 in American and Europe. Reprinted, with permission of JH Emerson Co.

[Massachusetts General Hospital] ordered one on the spot. You had one of the first that I built. There was a hassle, you know. Harvard was mad. There was a lot of back and forth. Dean Edsel asked me not to advertise for six months, which I agreed to. And in six months, the new Drinker came out with all the five features that had made mine good, without my advertising. Anyway, we survived that, and that's just a smattering of what happened.

So, let's go faster. That's a little one. You see how simple it could be. Just change the pressure inside by moving that handle. OK.

Now, in '36, there was an epidemic of flu, and Ralph Trabell was at Hartford. He wanted something better than the bubbling bottles. So, you remember for nasal oxygen they had these bottles just to—they were a tube under water, they would bubble. I wanted to split the bubbles up smaller. I got two bearings—from a Ford generator—that are porous bronze, compressed. I pushed the air through that, and I got little bubbles, like that. That was the first of a kind of humidifier where you broke the bubbles up real small. That was for Ralph Trabell, OK.

We did make one of the early IPPV [intermittent positive pressure ventilation] machines, too, and particularly for the Brigham, what was his name, [the] anesthesiologist there? What? Derek! Bill Derek. Bill Derek. We made an anesthesia machine ... a patient started to breathe, and it would assist them, and they tell me that it was the first with an anesthesia bag—you could encase or open the front of this thing and squeeze the bag by hand. That was in—well—later. Let's go on.

This is the chest respirator with a cage, which I made for bronchoscopy, for one thing, for the Long Island College Hospital. Anyway, I guess you know pretty much about that. Next.

This machine, you'd think maybe was an iron lung, but this is for Al Barach. This is one of the most sophisticated things we ever made. That was for treating tuberculosis, and the patient was completely enclosed. The Swedes developed this. A fellow named Thunberg, but he just put the patients completely in the tank and changed the pressures up and down quite rapidly and got ventilation by compression and rarefaction. If you press here on your chest, and bring equal pressure inside, the lungs won't move. But you can ventilate if you get enough difference in pressure. This thing worked, but for closing (what do you call them?) the holes in the lungs, but we must have made 60 of those, and just at that time the sulfa drugs were coming, so that was out the window. Next.

Oh, there's Derek's thing, see? '53 again. That's Derek himself and the bag, and you could open that and squeeze the bag if you wanted to. It was an assisting anesthesia machine. Next.

Incidentally, we made the first hyperbaric tank in the U.S. That was for Presbyterian Hospital in New York. They used that for a good many years. I went over to England and saw what they were doing over there, and then made this tank. Next.

You all know about that. One of the chest surgeons came to my shop a long time ago and, well, it was way before that, Glover and O'Neil, that was one of the teams in Philadelphia.

He said, "We're trying to expand the chest after our surgery with something they called a Stedman pump. I [used] 15 pumps and I still can't get the lungs to come up." I said, "You're doing it the wrong way." In two weeks or so I fixed him a little vacuum cleaner affair with variable speed. We were in business making these things and everyone uses them. Next.

This was for Jere Mead at the School of Public Health. His volume rather than the pressure plethysmograph, and a lot of people bought these for research. Next.

Al Barach—he wanted oxygen for his patients. When they went out walking, they wanted the security of having oxygen. And he wanted a walking cane for them to ... that's a walking cane with oxygen in it. It had 50 L in it. The FDA [Food and Drug Administration] didn't want it sold, because they'd set a rule that nothing less than 70 liters—you know, it all depends on—he found it useful for somebody trying to get up a few steps at their home. Anyway, let's go on. Next.

There's the belt we were talking of, see, that Barach was using. You could cycle it, or the patient could cycle it. Next.

This old ... would be related to the stories I'm telling you—(that's my wife)—and it is a good way for manual ventilation—it was a lot better than what was being used. I proposed the use of lifting the hips because you stretch the rib cage that way. You make it like a bellows, you see, instead of just pushing on the back the way the Schäfer prone pressure worked, which was the standard way of rescue in those days. Next.

That's the resuscitator we made. That again. Next. And that's the house that I traveled and sold iron lungs out of. I bought that on Commonwealth Avenue from [the] General Electric Company. They'd used it to sell kitchens. See the generators up in front? As I drove, I'd charge batteries, and then I'd come into a town. I could run the iron lung that I had in the back, and the town would go through and see the iron lung they were going to spend their money for. Next.

That's the lung now. Next.

Now, two more. I tell you, I'm going to skip these. No, just go one after the other. Yeah. The last one was a French iron lung (Fig. 3), which saved the day in the lawsuit for us. We found the one at the bottom there, and here I have the actual picture. But the thing that saved the day was this hospital [Massachusetts General Hospital] forming, because you had a library, we came here. We found references to negative pressure cabinets from the world over! Everyone there had thought that Drinker was the only thing, see. And we found people that had this idea in many countries, a good many people in this country. So, this Frenchman had a real cute idea. Instead of a pressure gauge to tell how well he was ventilating, [he used] a glass tube with a rod in it, and if the chest went up and down, he could see how much he was ventilating. Very direct. Anyway. Let's go. Next.

There's a French one (Fig. 4)—worked with a steam boiler. You shift the valve and it would ... and the Venturi. Next.

Just run them through. This was in Vienna (Fig. 5). Vienna again. This is England (Fig. 6). All these things, now, this is 1905 this thing was made in Tennessee (Fig. 7), Nashville. OK. This one and the next one were made in Massachusetts, or designed. OK. This was in South Africa, and the fellow had a patient and built on the spot an iron lung for himself and saved his case. Right on the spot! OK.

This was a plethysmograph that recorded. You could breathe

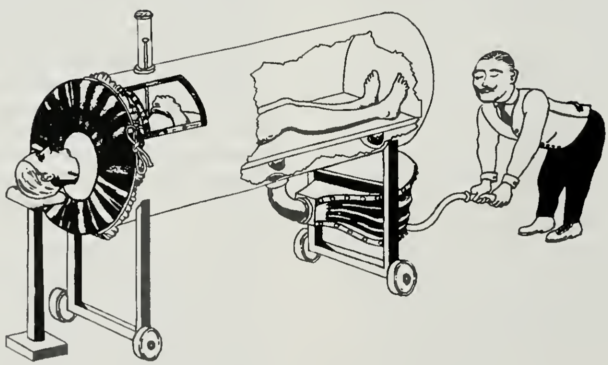

Fig. 3. In 1876 Dr Woillez of Paris built the first workable iron lung, which he called a "spirophore." It had the basic elements of modern respirators, including an adjustable rubber collar and a sliding bed. A unique feature was a rod which rested lightly on the patient's chest, to give visual proof of actual lung expansion. In a brilliant lecture presented before the Academy of Medicine on June 20, Woillez showed a thorough understanding of the physiology and mechanics of artificial respiration. He refused to patent his invention. A colleague suggested placing spirophores all along the Seine, for drowning rescues, but finances for the public service were lacking. (This illustration was reconstructed by Maxfield Parrish Jr for a legal battle ... .) Reprinted, with permission of JH Emerson Co.

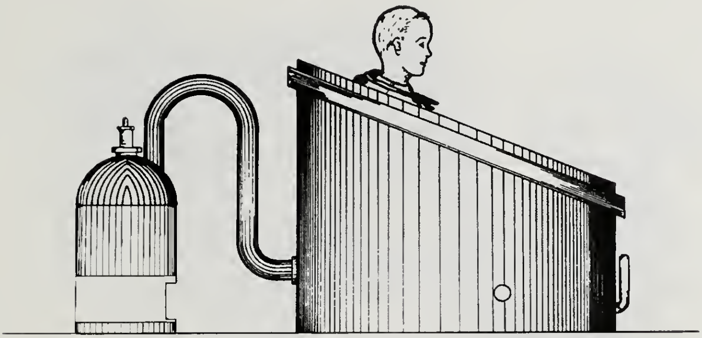

Fig. 4. Dr Charles Breuillard of Paris patented a "bath cabinet" type of respirator in 1887. For a source of vacuum he recommended "a stream ejector fed by a steam boiler ... heated by a spirit lamp." The patient himself was supposed to operate a valve, alternately connecting the cabinet with the vacuum, for inhalation, and with the atmosphere, for exhalation. Breuillard also described a chest respiratory "cuirass" to be operated in the same, and a face mask. Reprinted, with permission of JH Emerson Co.

dogs with it. All these were negative pressure cabinets. Go ahead.

This is do-it-yourself in Germany. OK.

And that's the Drinker, you see, with the pump and stuff and the rectangular tank. That was what was on the market. Next.

That's a room they had in Children's Hospital (Fig. 8). Five patients were taken at the same time. Negative pressure. OK.

Now, we found that Alexander Graham Bell had actually made one that was in the museum up in Canada. I believe we found reports that he came down to this hospital and tested it. I think he used to come to this hospital. OK. I have some information about that. [Responding to an unintelligible comment from the floor.] There it is. The thing to the left is what he called the jacket. See, it's a pot tank concealed up here and down here. And that's the pump. See the bellows? OK. That's it.

I'm out of breath from trying to rush. I probably shouldn't have tried the pictures. [Question from the floor about development of positive-pressure ventilators.] Well, let's see what I can give you on how the ventilator came about.

I guess it's related to polio. Actually, I think around '52 or something like that, they had an epidemic in Denmark and there weren't enough iron lungs. They couldn't possibly get

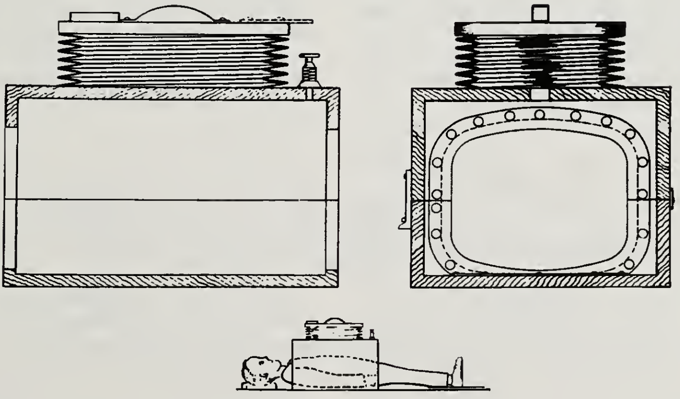

Fig. 5. In 1901 Rudolf Eisenmenger of Piski, Hungary, patented a portable respirator which consisted of a "simple, two-part box" enclosing only the patient's chest and abdomen. Later he became medical professor in Vienna, and there continued to improve his invention. He stressed the importance of access to the patient's throat and limbs, of portability, and of hand-operation. (Motors were also mentioned.) There are reports of "extraordinary success" with Eisenmenger's respirators. Reprinted, with permission of JH Emerson Co.

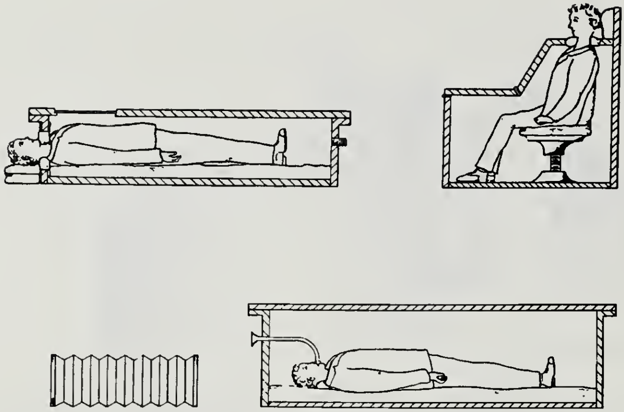

Fig. 6. William Davenport of London understood the mechanics of artificial respiration clearly. His patent in 1905 mentions a box, a rubber collar, and a simple bellows or piston pump. He lacked the sliding bed (of Woillez and modern iron lungs) but made several good suggestions, including the supplementary use of oxygen. He proposed several types, including a "collapsible form ... to facilitate transit." Reprinted, with permission of JH Emerson Co.

enough iron lungs. Any of you heard this story? You know about it? They got all the anesthesia machines they could find in the countryside and set up students squeezing anesthesia bags and kept those patients going, and they survived! A lot of them. Their survival was as good, I guess, as the iron lung cases' survival, so (I guess I'm not very polite this morning), but that brought a flood of anesthesiologists from Denmark over here. I think one of them is your Dr Pontoppidan. Dr Rottenberg is another one. Mörch is another. I guess there were maybe a dozen [who] got over here to show us how they'd done things.

Mörch was in Chicago at the University of Chicago and Cook County Hospital. He made a piston machine. As a matter of fact, just before Mörch, of course, it was the Engstrom. Maybe they were both around the same time, but they were both piston machines. They were equal cycle, in and out, and Don Benson worked with Mörch on his machine. His, incidentally, went under the bed. Mörch's was a low machine, about that size and so high. And the drive was horizontal, so the whole thing could shove under the bed where you couldn't see it. Then he had a tube up to the patient, and an exhalation valve, which was a big steel ball that would pop up and let the patient exhale.

Anyway, Benson moved to Hopkins and he made himself a piston machine that he hoped would have better humidity, because that was one of the problems with the machine that Mörch had made. They still weren't trying to use very high pressures, because everyone thought you shouldn't use pressures above, oh, 20-25 cm H_2O. He had a water kettle and heated it. Then the gas that came out of the water kettle [passed

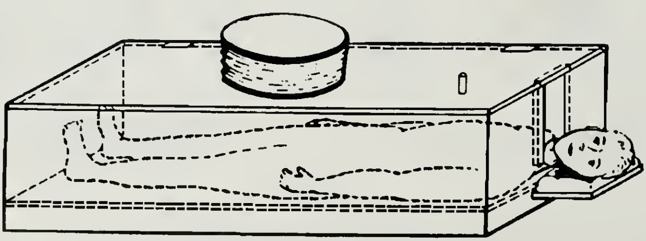

Fig. 7. Dr Charles Morgan Hammond of Memphis, U.S.A., built his first "artificial lung" in 1905 and a series of improved models throughout the next 20 years. He performed experiments and treated patients successfully, but his respirators were not produced commercially and remained unknown to the public for many years. Reprinted, with permission of JH Emerson Co.

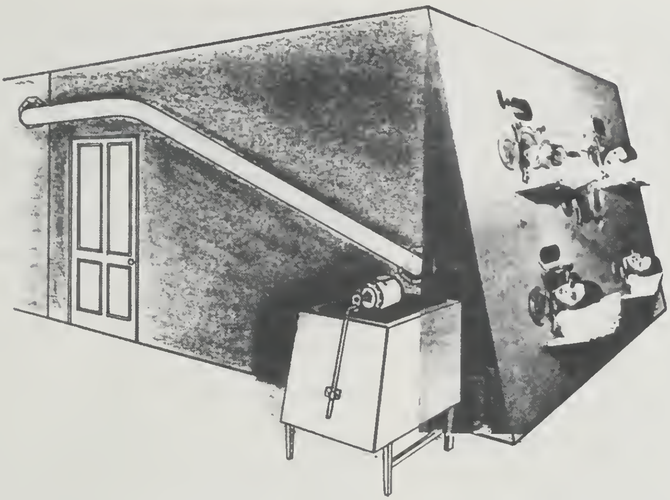

Fig. 8. In the early respirators it was difficult to give complete nursing care and to change the patients' position frequently. This care was found to be of life-saving importance, so Dr James L Wilson asked for a room in which several patients could be made to breathe simultaneously. A nurse could enter by the door and perform all procedures efficiently. The room pictured was built at the Children's Hospital in Boston, U.S.A., and was used successfully during several epidemics. Reprinted, with permission of JH Emerson Co.

through] this copper wool which you've seen in our machines. First, the main reason he put the wool in was because it was conductive. It would conduct the heat farther up the line, closer to the patient, and keep the humidity high and warm. He couldn't get any of the big manufacturers interested in making this thing for him, so one day I got a call from him. He wanted to know if I was interested, and I said "Surely." I went down to see him, and he told me why he built it and said he thought the people would want this thing.

So, we went back and worked on it for a year. I was involved in making underwater swimming stuff for the Navy, and I'd done that because the iron lungs had dropped out of the picture, pretty much, because of the vaccine. So it took us about a year to get a machine that we thought was about right. Benson wanted equal inhalation/exhalation time. He said he didn't want to worry about trying to have that variable. It was just a crank and a piston. Just as I was almost ready to take it down and show it to Benson, I get a call from Pontoppidan. Well, he'd been working here on a piston, I think he had Harvard Apparatus [a company at Harvard] get some electronic circuits made so that he could have I-E ratio variable. We knew from the polio days that with some of their cases, they wished they could have it not equal. So, I realized it was an important thing. We decided we'd hold up and try to add Pontoppidan's on top of what we made for Benson. That was the way the 3-PV came about.

You see, all the things I've done have been because doctors have come to me with something they were trying to do. We didn't set out and say, "Now we're going to get in this field and make this." It's because of what doctors asked me for. That's the way my business is run.

Now, the next step I want to explain to you is why you're doing a lot of things you're doing now for rescue—the cardiac resuscitation you're doing as opposed to what was being done back then. In those days, they used Schäfer prone pressure for breathing, and a few people were questioning that. Researchers were saying, "Well, it doesn't even move the dead space. How can you ventilate a patient that way?" So, at any rate, the Army had a problem with chemical casualties. A friend of mine, Jim Elam, an anesthesiologist, also, I think he was in Chicago, for his tour with the army, he went down to Edgewood Chemical Center with a Dr Clements (you've probably heard of Clements—he's now at the University of California at San Francisco) to try to find out how to save these chemical casualties, and the way they started, he asked if I'd let them have a resuscitator.

Now, our resuscitator was pressure-limited. Went up to 18-cm positive pressure, and it went down to a negative phase of 9 cm, and went back and forth. Six months later he called me up and said, "We aren't getting anywhere. Those dogs all die. We give them the gas and we can't resuscitate them. I wonder whether you could make that thing go to any higher pressures." I said, "Sure." He said, "Well, make one that goes to 50 for me." And the dogs all lived! This was supposed to be a pressure that was dangerous. Of course everyone understands it now, but they didn't then. That if the patient's stiff enough, it's perfectly safe to put the high pressure on.

So a big meeting was called down there, and for one thing they decided that they ought to throw out the Schäfer prone pressure, and Elam and Clements were advocating mouth-to-mouth, because that's about all you'd have out on the battlefield, and you could generate enough pressure to save these cases, they felt. So, the meeting, I think NIH [National Institutes of Health] held it in Washington, and Dr Whittenberger was chairman. Now, Whittenberger was at the School of Public Health here. He used to visit our place up in Essex with his family. One day, just before the meeting, he said to me, "You know, a dog when he pants, he doesn't move more than a seventh (I think he said a seventh) of his dead air space. But the dog lives. Maybe it isn't as serious as they're trying to say about the Schäfer."

That triggered something with me. It got me thinking about high frequency, about rapidly vibrating. I got so excited about that that I got a patent back then. I guess you know I got a patent around 1955. I made a machine to do this, but I couldn't really get anyone too much interested in it. But that was the reason, and people ask me why I did this, you see.

The other thing that was going on down there in Baltimore, of course, you know about Kouwenhoven, an electrical engineer at Hopkins. He was having trouble with the doctors, too. I mean, I don't know why I say 'too,' but ... he would go to meetings, showing how he could push on the sternum of a dog and circulate blood. Up to that time, the doctors had been—if you had to try to start the heart up—they'd been chopping you open and grabbing your heart and squeezing it. Now, these two things were put together, and that's what makes your present cardiopulmonary resuscitation.

The next addition to our machine, we went down to Gainesville in Florida, and Dr Downs and Dr Kirby ... I'm going to back up a little bit, because I believe that before that, again in this hospital, they were trying to get heat, and we made some things for them to retard inhalation, but the people in Gainesville were using what they called 'constant positive pressure.' Now, I go to my father's thing, which Barach said to him was the classic paper on CPAP [continuous postive airway pressure]. Alvin Barach had been trying to get people to see the value of positive pressure, constant positive pressure. In 1940, well, he wrote a lot about it, but I think my father's paper,* well, it was the earliest thing he could find where the suggestion of raising the pressure somewhat could be beneficial.

Anyway, Downs and Kirby had our ventilators down there, but they wanted, they were trying to get manufacturers to put constant positive pressure, be able to raise the pressure, CPAP they called it. Puritan Bennett wasn't interested. They said, "We're selling our machines. We don't care about it ... " Forrest Bird was working on it for Downs and Kirby, and so, of course, he had it. He made the one for Kirby for babies, but was unable to come up at that time with one for adults. And so, that's when they came and said "Can't you make this machine to be positive?" So, the next step was adding that to our machine. Of course, our machine was far better suited for it than any other machines there were on the market, because they all had pumps that they can shove gas through so they're small piping systems, and our machine was already made so you could breathe very, very freely, and I think that's one of the great benefits—I guess you all know that—of our simple machine that we have, ventilator. So we added that on to the machine, and now I don't know what else there is on it. Kirk, you tell me.

Kirk: Well, there's updated alarm systems.

Emerson: Oh, alarms, I haven't talked about. I had the first patent on the alarm for a ventilator, I believe, on the iron lung, and I had a lot of misgivings about it, and I still have a lot of misgivings. To tell the truth, I think you've got your ventilators so complex that there's a lot of trouble ahead. Do many of you people know about the present ... problems [of a ventilator manufacturer]? You do? Well, they are the little piston machines. They've jammed [the components] in so small and tried to add so much into them, that they can't keep them running. Now, the big machines, of course, I think we still have the most reliable breathing machine or ventilator on the market. We had troubles, but they've got so much electronic stuff that it's prone to breaking down, and then they try to make up for it by putting a whole bunch of alarms on, and before you get through, it's a bunch of alarms and machines that just isn't reliable. I don't know how far you go. I've been on the standards committees and they're going to demand more and more sophistication. I think they're going to go on getting into more and more trouble. For instance, [for] home care, what [their ventilator] is for, they say ours is definitely the most reliable by far, our big machine, but they can't drag that into a home. It's too big, you see. We haven't really tried to make it much smaller.

Anyway, I thought I might see if anyone had any questions, anything anybody would like to ask me about the history that I might know about.

Unidentified Member of the Audience: We took your machine into a home in Somerville to help a child, who—when this child would go to sleep at night—would stop breathing. This child's had this machine in the home for the past 13 years, and I remember going out there 13 years ago, to this old rickety house, dark night over there, and going into this home and the machine was there next to a wardrobe next to the bed, and this child was being ventilated. The mother called me because apparently the child was getting a little blue at night,

* Emerson HA. Artificial respiration in the treatment of edema of the lungs: a suggestion based on animal experimentation. Arch Intern Med 1909;3:368-371. Reprinted on Pages 583-584 in this issue, with permission.

and she thought the machine may need some adjustment. While I was watching the child being ventilated, lying there very quietly, this child was about a year of age, I saw the tubes from the child's tracheostomy to the machine wobbling in the breeze. I had no idea why, because I wasn't touching the tubes. I looked down and I saw the family cat there. He was clawing at the tubes. And I was trying to picture this scenario in the home with my intensive care unit ... in Burnam Six. It is really doing a remarkable job, and this child is 13 years of age and has lived at home on this respirator and is a thriving child. He goes to a normal school.

Emerson: Well, Children's in Philadelphia sent many children home on our machine, and also Children's in Chicago, and maybe you have, I don't know. This Children's has here. One of the real problems now with this [manufacturer's] machine, though, is that, for instance, Dr Goldberg at Children's in Chicago has all these people at home. He's pushed to get standards on these things, because there have been so many problems. Now the FDA has closed the door to this company—won't even let them sell parts. I can't understand that, because I don't know how they'll resolve it, but here they have all these patients with machines that are breaking down, what do you do? Anyway. Anybody else got any questions on the history?

Stoller: Well, what's on the horizon? I mean, given the fact that things are getting more and more complicated and probably should get less and less complicated, how's it going to go? What do you think?

Emerson: Well, I think they are going to find uses for high frequency. Is anything happening with that here?

Unidentified: Not a lot, no.

Emerson: Not even with the pediatrics?

Unidentified: They want to use it down in lithotripsy ... to minimize the movement of the patient who's being treated with the lithotripsy.

Emerson: That's really sort of a problem, that is high frequency, because the FDA says you can't sell a machine that goes faster than 150 [breaths per minute]. And that isn't really high frequency, you see. And so everybody's confused. They don't know what they're talking about. High frequency really should be substantially higher than breathing rates, and Kirk and you people have used our standard ventilator at 150 right here in the hospital, and people aren't calling that high frequency.

I've made two types of very simple high frequency machines. One of them is an interrupting affair, which they use at Children's successfully. And quite a few other places—down at Hershey Medical Center and Orlando General Hospital they've been using it. They've been doing it, in fact, the Critical Care show—this last one—had an exhibit on what they're doing down at the hospital in Orlando.

Now, the other one is an oscillator, which is what I described originally, the motion down, just a diaphragm or a piston. They used that successfully at San Diego Children's ... Mannio and ... Kopotic ... . Now the NIH has finally come around—Mary Ellen Avery, because of the success they had at Children's, was pushing to have a test, an NIH-run test. NIH has set up to run the test and they asked all the manufacturers to bring machines down to Miami a year ago, and they were going to rush through getting this machine, 100 machines, putting them in 10 hospitals, and finding out what happened if they put the machine on every other baby that needed to be ventilated in the first 24 hours. Well, there were about six manufacturers, and they chose a machine that had not been made yet. I think it's absolutely outrageous what they did. Getting a machine called the Hummingbird that [a company in Japan] agreed to make. They hadn't made it yet for babies.

On Tuesday I'm going out to a meeting in Salt Lake. Dr Harris, a neonatologist at Temple, runs these meetings. They're going to have a discussion of this. I guess the NIH is going to be there and try to explain what they're doing—why they've done this. Again, Kopotic set up with our simple oscillator, it couldn't be simpler. And incidentally, right after the decision to get this Japanese machine—the cost is going to be $30,000 per machine—you know, they really don't care. Anyway, I'm going to go out there and see what happens. I'm going to show my machine. You know, they want to have it there, and Kopotic and Mannio are probably going to describe the thing. But right after their decision, I got orders from three good California hospitals, Stanford, Sunshine—Dr Sunshine and Loma Linda—and the University of California at Irvine where Dr Whittenberger is, and Kopotic was going to show them how to use them. I don't know how they made out with them. I'll find out, probably, at this meeting.

Unidentified: Two questions. The first one: in a very limited sense, we could use on occasion in the operating room a high-frequency ventilator with which you can also give anesthesia. I don't know if there are any on the market, but people have tried to put them together, but that's not currently available, as I understand it, for us to use. We have a high frequency ventilator in the O.R.—a small box.

Emerson: Well, it isn't really high frequency. It doesn't go over 150.

Unidentified: I don't think so ... it's a jet ventilator. It works for the short term, but we have no ability to give anesthesia.

Emerson: In fact, they've been doing that this way, the same darned thing. I may come to do that. Well, if Kirk can tell us what you want, I made one which they wanted, the same thing in Florida over at Clearwater, and I made it for them, and I got it back here. It's hard to work with somebody in Clearwater. It's too far away. If you want to try one of those slow kinds of things, now I've made—see, with FDA, you can't do these things anymore.

Unidentified: That was my second question, actually. Could you give us, as you've gone through the history of what you've done—you went through it very quickly and it sounded a lot easier than it probably was—but in today's times versus in the 30s and 40s, the bureaucracy is so deep.

Emerson: It's terrible. Look, I built my iron lung essentially in two weeks. I slept in it one night, and put a patient in it. And it worked, see! I don't think that the FDA should have been given the authority by Congress or whatever it is to put the identical rules that they have for drugs. I think there should be some control, but I don't think that they are equivalent, you see. I think the mechanical thing, you know better what it's going to do, but it's very difficult to do; in fact, I don't know, I often think of going out of business. Of course, I have the same trouble all the doctors have of lawsuits and stuff. Life is different. We're going to go on, till we get put out of business.

Unidentified: It seems that there are a lot of things that are written that say that the nondemand valve ventilators are very good, but one thing I've noticed is that some of the other ones are much prettier than yours. How much is appearance important in your sales or in sales of ventilators?

Emerson: Oh, I hear a lot of that.

Unidentified: I think the Emerson is pretty.

Emerson: I don't know what to say about that. I know the old green machine looked like a household appliance. But it worked.

Unidentified: Do you find that the hospitals would get rid of those, even if they were still working, to get a new machine?

Emerson: All right, that brings up another story. Who's going to ... He isn't here anymore? Who's going to Cleveland Clinic?

Stoller: Oh, I am.

Emerson: Oh, there you are! I was looking for you.

Stoller: I had to sit down. I was going to ...

Emerson: Who came from this hospital and took over the anesthesiology department at Barnes?

Stoller: Bill Owens.

Emerson: Bill Owens! I was trying to think of his name. Well it seems to me that maybe the same thing's going to happen at Cleveland Clinic that happened at Barnes. Bill Owens trained here, right? And he went down there and he threw all their MA-1's out for his intensive care unit. He went down to the cellar and found about 18 of our machines that they had discarded. He brought them up, and they did a show themselves. They painted them; they looked like Rolls Royces. They have padded covers that go over them. They're beautiful! And that's what they use in their intensive care. Now, I understand that in Cleveland Clinic, they had an anesthesiologist who used our machine for all their anesthesia for their heart surgery. They simply fed anesthetic gas into it. And then he left. They threw them all out. It's an awfully inefficient system, I must say. Maybe you've got someone here who's going to ...

Stoller: I'll give you an update.

Emerson: So, anymore questions?

Unidentified: Was James Wilson the same James Wilson who went to Michigan as chairman of pediatrics?

Emerson: Absolutely wonderful guy! Yeah. He got me started on the iron lung. I think I've gone over time.

Artificial Respiration in the Treatment of Edema of the Lungs: A Suggestion Based on Animal Experimentation

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On three separate occasions, in 1906, 1907 and 1908, while demonstrating the effects of extreme peripheral resistance on the heart and pulmonary circulation, I have noticed a definite result of artificial respiration when administered to an animal apparently dying from acute pulmonary edema.

The physical causes of the benefit apparently derived from this procedure seem to agree so well with facts already accepted in physiology, and the possibility of application of the method in certain kinds of clinical cases seems so reasonable, that I offer this communication in the hope that practical tests may, before long, be sufficiently conclusive to establish its value therapeutically, or to relegate it to the mass of theories that have failed.

It will save time if I call attention to a few points regarding the effect of respiration on the circulation. The respiratory fluctuations in blood pressure which anyone can appreciate in the radial pulse are due to the variation in the ease of passage of blood between the right and left side of the heart and to the inherent elasticity of the lungs. The expansion of the lungs allows a wider path for the blood and an increase in the blood in the pulmonary vessels, and at the same moment a diminished resistance to the passage of the blood through the lungs, a lessened burden for the right ventricle. When the lungs collapse in expiration, the elastic recoil empties the pulmonary vessels, and at the same time narrows the path through which the right ventricle must now pump the blood. So we find in the last two thirds of inspiration and the first third of expiration a rising pressure, the remainder of the respiratory cycle showing a falling pressure.

If we watch the results of positive pressure respiration properly applied, we notice an entire reversal of the blood pressure changes above described. During the inspiratory phase, which is due to the forcing of air into the lungs under positive pressure, the normal conditions in the chest and in the pulmonary spaces are altered. The positive pressure exerted on the vessels in the lungs tends to empty them, or at least to obstruct their lumen, by just the amount of pressure exerted. The small vessels are squeezed, as it were, against the resistant pulmonary tissue, by air forced into the terminal vesicles through the trachea. During the expiratory phase the release from positive pressure permits a filling of the vessels again and a diminished resistance to the passage of blood from the right to the left heart. So it will be found that during positive pressure respiration, the so-called artificial respiration of laboratory procedure, the blood pressure falls during inspiration and rises during expiration.

For our present purposes the important thing to bear in mind is that rhythmical variation of pressure, applied at any point of the circulation, will serve to assist in the onward movement of the blood, and will in proportion to its extent assist the action of the heart. It has been found possible to continue a circulation of the blood simply by artificial respiration in an animal in which the heart is no longer capable of contracting, the valves allowing an onward movement with each inspiratory phase and preventing any regurgitation to fill the vessels during expiration.

If we modify the procedure of Professor Leo Loeb, who first called my attention to the use of adrenalin to cause edema of the lungs, we can develop gradually an acute cardiac insufficiency. Massive and repeated doses of adrenalin given intravenously in a cat will produce acute dilatation of the left ventricle, due to sudden and extreme constriction of all the systemic arteries. The dilatation of the left ventricle allows of a mitral regurgitation, an acute congestion of the lungs and a dilatation and failure of the right heart. The inability of the right ventricle to force the blood received from the auricle against the back pressure of blood regurgitating from the left auricle allows of increase in the stagnation of the pulmonary circulation. Edema—that is, a collection of blood serum in the air spaces of the lungs—occurs, increasing until pink or clear serous frothy fluid appears in the trachea. Respiratory movements become exaggerated and later feeble and spasmodic, and the animal will presently die of asphyxia due to a flood-

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From the Department of Physiology of the College of Physicians and Surgeons of Columbia University in the City of New York. Read at the meeting of the Section on Medicine of the New York Academy of Medicine, March 16, 1909.

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ing of the air spaces of the lungs by blood serum.

If, when we find respiration showing definite signs of beginning asphyxia, when the veins are becoming distended and deepened in color, cardiac insufficiency is established and the incompetency is increasing, and when we can hear moist râles over the lungs, and when we know that cardiac insufficiency is established and the incompetency is increasing, we then apply artificial respiration through the tracheotomy tube, gently distending the lungs and allowing them to collapse with or without suction, we shall find presently an amelioration in the animal's condition. The full expansion of the lungs, due to distention from within, forces a considerable amount of blood onward to the left auricle, and as the respiratory phase extends over two or three heart beats, an increased amount of blood will have passed the mitral valve and there will be more room in the pulmonary vessels when expiration occurs for the blood held in the distended right ventricle, and a diminished resistance in the lungs against which the right ventricle can now successfully empty itself.

This at least seems the probable explanation for the improvement in the circulation which presently occurs. The lungs appear free from moist râles, the heart beats more vigorously, the distention of right and left side diminishes and when the artificial respiration is discontinued after about half an hour the animal is able to breathe normally and shows none of the signs of insufficient circulation or respiration. The effect of the adrenalin has worn off, the heart muscle has recovered from its acute overloading, the pulmonary circuit is no longer engorged with regurgitated blood, and to all intents and purposes the heart and lungs are again performing their functions normally.

The bearing of this purely experimental procedure on the individual case of edema of the lungs in the human subject may not appear quite clear, and I shall try to point out the conditions in which I believe this lesson can be applied with advantage.

In many instances a hypertrophied and properly compensating heart, which has adjusted itself gradually to a valvular defect or to an increasing inelasticity of the arteries or persistent increase of peripheral resistance from any one of a number of causes, will, if a sudden strain is put on it, develop an acute incompetence. Overexertion physically, overindulgence in food or wine, excess of psychical excitement or an unfortunate combination of all three, or an attack of contracted arteries or bronchi may be the determining factor. With a heart just able to maintain its competence under favorable conditions, even if it is not the seat of myocardial degeneration, insufficiency is easily precipitated and pulmonary edema is likely to be developed unless the failing heart action is of very brief duration. Under such conditions as I have above described, I believe it would be a valuable aid to the necessary medication if artificial respiratory movements were used. With the patient in the semirecumbent position, which is usually assumed when cardiac dyspnea is marked, raising the arms above the head and then pressing them against the sides of the thorax or, better, across the upper part of the abdomen, ought to establish the accessory pumping action which, under normal conditions, facilitates the flow of blood through the lungs, but which the patient, in his enfeebled condition, is unable to do for himself. This assistance, I believe, should prove more prompt and effective than any medication, and would at least be giving mechanical relief to the overloaded heart muscle, while arterial relaxation and cardiac stimulation are being accomplished by drugs. I think such treatment would be indicated whenever the edema and cardiac incompetence are of sudden development and are due to causes which are likely to prove of brief duration or can be removed by appropriate treatment. Edema, when due to cardiac failure in the course of pneumonia or appearing as the inevitable terminal feature of a chronic endocarditis, could not be expected to respond to such temporary relief as artificial respiration would offer. Moreover, I hope I shall not be misunderstood as advocating forced respiration by intubation or tracheotomy, for I certainly think such measures would be quite unjustifiable. My belief, based on experimental observations, is that artificial respiratory movements, directed to establishing a rhythmical expansion and contraction of the thorax, are worthy of clinical trial in cases of acute cardiac insufficiency accompanied by edema of the lungs.