On the very first, successful, long-term, large-scale use of IPPV
Albert Bower and V Ray Bennett: Los Angeles, 1948–1949

Ronald V Trubuhovich

Mechanical equipment plays a major role in caring for acute poliomyelitis patients with respiratory involvement. The purpose of this equipment is to keep as nearly normal as possible the physical and physiological environment for maintenance of life and recovery of the patient.

Albert Bower et al (1950)\(^1\)

Preben Berthelsen and Michael Cronqvist (2003) identified Bjørn Ibsen’s 1953 multi-purpose intensive care unit at The Community Hospital (Kommunehospitallet) in Copenhagen, which used intermittent positive pressure ventilation (IPPV) for respiratory failure, as “the first intensive care unit in the world”.\(^2\) Taking their lead, I have tried to find the very first successful use of extended IPPV on a large scale, as recorded in medical literature written in English. It appears to have been applied during the Los Angeles (LA) polio epidemic of 1948–49,\(^1,3-5\) by the Communicable Diseases Service\(^{FOOTNOTE [FN]A}\) of the Los Angeles County (General\(^7\);FN-1B) Hospital (LACH), Boyle Heights, Eastern Los Angeles, United States, under the care of physician Albert G Bower (Figure 1), biomedical engineer V Ray Bennett (Figure 2), and their medical, nursing and supporting services teams.

After September 1948, intratracheal positive pressure ventilation was produced by a “(Bennett)\(^{FN-1C}\) positive pressure respirator attachment” (BPPRA) adapted to the Drinker–Collins intermittent negative pressure ventilation (INPV) respirator,\(^1,3-5\) to substantially augment the artificial ventilation (AV) delivered. This article will describe some features of these pioneering achievements. But because its major interest is the treatment of acute ventilatory failure in acute polio.

An “unprecedented respirator patient load at Los Angeles County Hospital [LACH] in 1948 (294 respirator cases)” arose from a seasonal increase in poliomyelitis cases to near-epidemic proportions. A finding by physician Albert Bower and his team that respiratory acidosis was frequent in patients receiving intermittent negative pressure ventilation (INPV), together with their awareness of a previous high mortality rate due to the standard treatment of polio ventilatory failure with Drinker–Collins respirators, led to multiple advances in equipment technology for LACH.

Most important was biomedical engineer V Ray Bennett’s positive pressure respirator attachment, in use after September 1948, which converted an INPV machine, the Drinker, into one capable of supplying “intratracheal” intermittent positive pressure ventilation (IPPV), supplementary to its NPV. Together with their teams, Bower and Bennett used this attachment for 73 of 1949’s 130 “respirator cases”, to establish the first-ever large-scale long-term success of IPPV for respiratory failure in acute polio. In 1949, they demonstrated the superiority of (supplemental) IPPV over INPV alone, achieving a survival rate of 83.7% (108/129) — compared with the 21.1% survival rate in 1946 among the 38 patients ventilated that year.

A complete system of respiratory care was developed for polio victims at LACH, setting levels of treatment and expertise distinctly higher, by 1950, than was current at other known polio respiration units, and preceding the well known developments in Copenhagen in the early 1950s. Extensive experience was obtained by a consistent medical staff, working as a team, in one hospital.

Bower and Bennett deserve greater recognition of their pioneering merit than they currently receive in the written history of intensive care medicine.

**ABSTRACT**

An “unprecedented respirator patient load at Los Angeles County Hospital [LACH] in 1948 (294 respirator cases)” arose from a seasonal increase in poliomyelitis cases to near-epidemic proportions. A finding by physician Albert Bower and his team that respiratory acidosis was frequent in patients receiving intermittent negative pressure ventilation (INPV), together with their awareness of a previous high mortality rate due to the standard treatment of polio ventilatory failure with Drinker–Collins respirators, led to multiple advances in equipment technology for LACH.

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**Footnote 1. Concerning nomenclature:**

**A.** There appears to be little consistency used by Albert Bower and others in the descriptive words naming the Los Angeles County Hospital department: whether Contagious\(^1\) versus Communicable;\(^3-7\) Service\(^1,3-4\) versus Unit;\(^4,7\) Disease\(^3,4,7\) versus Diseases.\(^3,5\) For instance, within the 1950 two-part principal paper, the first part is recorded as from the “Contagious Diseases Service”,\(^1\) the second from the “Communicable Disease Service”.\(^3\) Elsewhere, for the same year 1950, it was the “Communicable Disease Section”.\(^5\) The term “Unit” does not appear used other than in the years 1949\(^7\) and 1954.\(^4\) Confusing!

**B.** The word “General” appears to be incorporated within the LACH name only once, in reference 7.

**C.** Bower et al usually write about the Bennett inventions with the name Bennett bracketed in this way.

**D.** Bower et al’s term “Resp. Patient”, as used in their Table V, page 687 of reference 3, at times confused me as to its precise meaning. Whether to take it as meaning respirator or respiratory. His classification of “Respirator Patients” included non-ventilated ones (see Footnote 2; and also [my] Table 1 in this article).
the LA polio patients by AV, other acute aspects of their polio will not be pursued.

Poliomyelitis at Los Angeles County Hospital, 1946–1948

The Communicable Diseases Service of LACH provided a major receiving centre for patients with acute poliomyelitis. The basic respirator used there at that time was the Drinker–Collins cabinet respirator, a standard “negative pressure” body-type tank; later, some other Drinkers were supplied in giant and junior sizes.4[p.149-50] There was also at least one Emerson respirator.3[p.693] 1946: Experience from the influx of patients proved salutary: Bower, Bennett et al classified 48 of the 1284 acute polio admissions as “respirator patients”.3[p.687];FN-1D,FN-2 These 48 patients (including eight “bulbar patients” who were not ventilated) suffered a 79% mortality rate; among the 40 who were treated with INPV, 30 deaths still gave a mortality rate of 75%.3[p.687] To what extent the AV treatment was apportioned between Drinker versus cuirass respirators is not recorded — the latter were mentioned, but without data.4[p.150] It is evident that tracheotomy was used freely when indicated,7,1[p.574] although, as Bower recognised later, probably not every time that it should have been.3[p.687]

Curarisation (with d-tubocurarine, as Intocostrin [Squibb])4[p.44],7[p.254] was first studied for polio patients at LACH on 17 August 1946,6 and employed where needed, to ensure synchronisation between patient and respirator.5[p.264],6,7

As well as what appears to have been exemplary respiratory therapy5,7 and treatment of complications, appropriate attention was paid to routine care, such as supporting circulatory status, ensuring adequate nutrition, and correcting biochemical, especially K+, abnormalities.4,5,7

1947: Total admissions the next year eased to 402, but two thirds of the 21 “respirator patients” still died (it was not stated how many of these were ventilated). The deaths represented 4.1% of the LACH total year’s polio patients, comparable with the 3.8% total case-fatality rate for 1946.3[p.687]

Footnote 2. Note that in Bower and Bennett’s accounts, a patient’s being classified as a “respirator case”4[p.687] did not necessarily indicate artificial ventilation would be provided. Thus, although all the 1949 “Resp. patients” were ventilated, “adequate equipment was not available for all [1948] acute cases”.

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In 1949, Bower and team member Dr Harold West wrote that they were convinced their treatment (meticulous respiratory care, often with tracheotomy) “during 1946 and 1947 ... saved about 50% of patients of a type [those requiring AV] that previously died”.7


Clinical studies to September 1948

Early in 1948, Bower et al conducted a study of their patients, to reveal facts, “startling in their implications”.5[p.262] Acutely ill patients placed in INPV respirators could later be found in a state of profound respiratory acidosis,3[p.691] for 30 patients among 294 respirator cases in 1948, standard ventilatory measures for eliminating excess CO₂ had failed.

Further, Bower found, “In most cases with so-called respiratory center involvement, ... it is remarkable how rapidly measures which provide a clear airway and, adequate breathing can clearly show the error of this diagnosis.”4[p.3] Also, in a patient presenting either with convulsions or coma, “anoxia or pulmonary acidosis from too much retained CO₂ … must be prevented or corrected to rule out encephalitis”.5[p.189] William Frank confirmed “most so-called encephalitic signs disappear when respira-
tory inadequacy is corrected"; this has recently been discussed again. However, electroencephalography indicated that clinically undetected encephalitis occurred more frequently than believed.5[p.188]

**Bennett flow-sensitive positive pressure breathing unit**

Multiple respiratory devices already invented by Ray Bennett were being used clinically. His *mobile* Bennett flow-sensitive positive pressure breathing unit (BFSSPBPU), "in clinical use for several years prior" to 1948 was a "completely developed instrument",1[p.564] different from, and an improvement on, resuscitators available hitherto (Figure 3). Incorporating the Model TV-2P respirator (Figure 4), it was used "extensively" at LACH, mainly for respiratory emergencies or tracheotomy, or for short-term relief. Two units were in constant service there in 1948 and later.5[p.262] Hurley Motley and Joseph Tomashefski,12 following experience with the MSA Pneophore from the mid-1940s, had switchedFN-4 to Bennett’s TV-2P systematically, to deliver bronchodilators by intermittent positive pressure breathing for patients with chronic respiratory disease.12,4[p.110] The BFSSPBPU provided automatic cycling by pneumatic timing accumulators,1[p.565] but also allowed the patient to take control of breathing; it was run electrically from mains power (115 volts AC) or battery (24 volts); by hand pump or by high flow compressed gases (circa 15 L/min).4[p.152]

**Evolution of the Bennett (intermittent) positive pressure respirator attachment**

Bennett’s resuscitator, the BFSSPBPU, was needed to help meet the demand for AV at LACH during 1948, but it proved “less practical” for prolonged IPPV than his later positive pressure (PP) attachment — or even less than negative pressure ventilation (NPV) (Bower,4[p.152] Clarence Daj4[p.152]). So the BFSSPBPU “was not used routinely for prolonged patient care” (Elizabeth Austin4[p.112]). At West’s request,5[p.264] Bennett and the collaborating medical engineering team “quickly accomplished”5[p.264] an adaptation from the BFSSPBPU, called the (Bennett) positive pressure respirator attachment (BPPRA), fitted as an accessory to the standard Drinker–Collins tank respirator to augment the minute volume delivered1[p.561-3],5[p.264] (Figure 5 and Figure 6). It was powered by the motor of the NPV tank. PPV could be applied via a mask covering mouth and nose, or via Bower’s own5[p.262] newly devised tracheotomy adaptor. Bennett’s

*Footnote 4. They appreciated the valuable properties of the Bennett flow-sensitive cycling valve (easy to clean so it did not stick; no rebreathing) and of the compensated pressure exhalation valve (rapidly removed; readily cleaned).*12

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**Figure 5. The (Bennett) positive pressure respirator attachment**

A diagrammatic layout of functional parts of the (Bennett) positive pressure respirator attachment, including the optional humidifier attachment. (Reproduced with due acknowledgement to V Ray Bennett and his earlier publishers.1,3,5, and many thanks to Warren Sanborn and the Puritan–Bennett Corporation staff.)

**Figure 6. The (Bennett) positive pressure respirator attachment mounted to a Drinker–Collins respirator**

Front view of the (Bennett) positive pressure respirator attachment mounted to a Drinker–Collins respirator. (Reproduced with due acknowledgement to V Ray Bennett, Albert Bower and their earlier publishers.1,3,5)
Figure 7. A diagrammatic comparison of the cam versus a crank for actuation of the Drinker–Collins respirator

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special exhalation valve was installed adjacent to the mask or tracheotomy connector.1[p.565] The bellows attachment (see Figure 5 and Figure 6) was “easily installed without stopping the respirator, requiring only a few minutes”.4[p.156],5[p.262] Bower described it as “ingenious with its simplicity”.5[p.264]

In a regulated dual action,5[p.264] the BPPRA provided IPPV (together with humidification and, when required, oxygen and/or helium5[p.264]) down the intratracheal pathway to supplement the respirator’s externally applied NPV. Bower called this the “combined pressure” mode and saw it as “maintaining ventilation under almost any condition”.1[p.562]

It ensured a more effective ventilating volume than that from NPV alone, while allowing reduction in the INP used. Typically, a negative-pressure mode with a range of –21 to –27 cmH2O was reduced to –10 to –15 cmH2O for the combined mode; this increased the tidal volume. For example, for Case 50, changing from the tank pressure of –18 cmH2O by negative pressure (NP), to a combined pressure difference of 18 (derived from +9 PP with –9 NP) produced a rise in tidal volume from 300 to 400 cc (mL), while a tidal volume of 450 cc followed [+18] PP alone.3[p.690]

For needs such as taking the patient out of the respirator, IPPV could completely replace INPV (thus, the “positive pressure” mode) — but for short periods only, even though IPPV on its own could provide greater ventilation than NPV.1[p.561],3[p.691]

Certainly, the Drinker plus the BPPRA was in no way an IPPV machine in the way the 1951 Engström constant volume ventilator was, but a system of an INPV tank incorporating a device which, “by delivery of a sustained pressure of gas [PP of 5–20 cmH2O], rather than a set volume”,3[p.691] supplied supplemental IPPV “in exact synchronisation with the respirator’s cycle”.1[p.561][3][N.5]

Tables VI–XII of Bower et al3 indicate (incidentally) the size of the PP and NP components making up their “Total Effective Pressure cmH2O” in the combined pressure mode. The ranges in the studies vary: examples listed for patients were +15 with –17 to make a “total effective pressure” of 32 cmH2O3[p.690] or +7 with –7 to give 14 cmH2O; or +10 with –16 to give 26 cmH2O. Because the tables cover only some of the patients studied, one cannot determine for the combined pressure mode how often AV was essentially INPV augmented by IPPV, or essentially IPPV to a maximum of 20 cmH2O augmented by INPV. (The authors do describe IPPV as providing more effective AV, so presumably, they would favor it.)

Nonetheless, this appears to have been the first use of IPPV on a large scale, either as combined pressure or positive pressure alone.

Application of the BPPRA1,3,5

During October 1948 and through 1949, the LACH Service had use of 42 BPPRAs mounted on Drinkers. (It is not stated whether there were further Drinkers on site.) With 79 of 1949’s 130 “respirator patients” needing a respirator (and 89 a tracheotomy), the BPPRAs were “in almost constant use”.1[p.563] The authors do not state the relative frequency of employing the combined pressure mode to deliver AV, versus positive pressure or negative pressure modes. The BPPRA was also used at other hospitals on the US West Coast,1[p.563] such as Rancho Los Amigos Hospital (Downey, Calif); and at Washoe Medical Center (Reno, Nev) by William O’Brien and associates.4[p.234]

The BPPRA was later developed for sole use without a conventional tank-type respirator, enabling a patient, if then so able, to move around the bed.7[p.572] But need was being foreseen to develop a “completely new respirator design”, post-epidemic.1[p.582]

The rotary cam

Bennett adapted a rotary cam-actuation to 25 of the 42 Drinker machines, in place of the shank-actuation mechanism with its fixed sine-wave flow pattern1[p.567-8],4[p.162] (Figure 7). The cam, able to produce almost any type of desired pressure pattern, was adapted for a slower steady rate of

Footnote 5. “… ie, positive pressure to the patient’s lung during the respirator’s inspiratory negative pressure phase, and complete release of pressure during the expiratory phase to permit passive expiration into atmosphere at zero pressure”.1[p.561]
pressure rise and a longer flow during inspiration — nearer to the ideal. It allowed lower peak pressures (which are “more physiologically desirable”), and an inspiratory flow pattern (which could be varied) providing inflation that was more uniform, for better alveolar aeration.4[1.10]

During expiration, the cam allowed sudden release of pressure against ambient air with a rapid expiratory flow followed by a somewhat prolonged expiratory phase, both operating to cardiovascular advantage.4[1.108] (Two cases of circulatory impairment were recorded, apparently from inimical PPV.3[1.695]) When the BPPRA was used in a cam-actuated respirator, “greater advantages [were] obtained both in total ventilation and distribution of ventilation in the lungs”, compared with that from the crank-actuated respirator with its typical sine-wave pressure pattern.1[1.570] Thus Table XXX lists greater efficiency with the cam — between 11% and 43%, on average 30% — in a group of patients studied.3[1.710]

Many other equipment inventions or improvements were designed and employed for a complete system of safe respiratory care (see Appendix 1 and Appendix 2).

Outcomes with use of the BPPRA

The case-load of “respirator patients” at LACH in 1948 was 294, and 130 in 1949. Use of the BPPRA after September 1948 “virtually eliminated pulmonary acidosis in our cases and diminished or dried up secretions”.1[1.264] Though some results before October 1948 were available for the principal articles published,1,3 records were complete only for the next year. By 1949, the AV from a combined (or a positive or a negative) pressure ventilatory mode was “of significant clinical value for at least 130 acute respirator patients”, 82 of whom recovered to be completely out of a respirator. The 1949 death total among these was 22 — including one victim who was “dead on arrival” — a 16.9% case-fatality rate (which became 1.95% among the total of 1128 polio patients admitted in 1949).

This contrasts with a 79% death rate for patients ventilated by INPV in 1946 (see Table 1), although Bower notes that “if actual 1946 respirator deaths only are used, the respirator mortality remains high [62 per cent]”, still, for “Resp Cases”.3[1.687]

Apart from its use for the acute respiratory failure of polio, the PPV apparatus provided adequate ventilation during respiratory failure emergencies, to take the patient out of the ventilator for nursing procedures, tracheotomy, medical treatments or transfer.

The ventilation meter

To assist a patient’s impaired breathing, the medical engineering team developed a comprehensive system of respiratory and safety devices; most are listed with some details in Appendix 1.

It appears that the tool Bower et al used which was key for assessment and for successful and efficient control of patient ventilation was the reliable Bennett ventilation meter: a positive-displacement type, with low resistance to flow and with low inertia characteristics.1[1.231] This enabled “actual breathing measurements in serial fashion”4[1.231] of the volume of successive breaths or of vital capacity, at an accuracy always >95%, and usually >97%.1[1.567] It was used in comprehensive and detailed, progressive ventilation studies,3 which reported “only a portion of the data obtained”; many early tests were discarded as unreliable, and only significant and accurate data from “extensive” tests were documented.3[1.694] The data:

- indicated when there was need for intervention with AV (the studies could “strongly point to the importance of early measures to stop the progressive drop in respiratory function”);3[1.700]
- researched and validated the different modes of AV undertaken;
- testified to the degree of the meter’s own usefulness, and the reliance which came to be placed on it for ensuring effective AV; and
- contributed immensely to the dramatic fall in mortality rates.

Use of the meter enabled effective control of the AV being delivered.

Perhaps Bower et al underestimated the critical role of the ventilation meter. From study of their publications, it seems that, in the overall clinical context, their ensuring such careful control — “ventilation must be determined for each patient”4[1.114] (ie, be individualised) — helps explain a drop in respirator mortality. That reduction seems to me greater than could happen solely from the changeover in AV methods to allow IPPV supplementation. By the time of the LACH 1954 book,4 wider credit was given to use of the meter.

Table 1. Comparison of outcome statistics for patients from the years 1946 to 1949, inclusive*

<table>
<thead>
<tr>
<th>Year</th>
<th>Patient classification</th>
<th>Total cases</th>
<th>Survivors</th>
<th>Died</th>
</tr>
</thead>
<tbody>
<tr>
<td>1946</td>
<td>&quot;Respiratory&quot;†2[1.10,3,2]</td>
<td>48</td>
<td>10 (21%)</td>
<td>38 (79%)</td>
</tr>
<tr>
<td>1946</td>
<td>Ventilated</td>
<td>38</td>
<td>8 (21%)</td>
<td>30* (79%)</td>
</tr>
<tr>
<td>1949</td>
<td>&quot;Respiratory&quot;†</td>
<td>130 (1 DOA)</td>
<td>108 (83%)</td>
<td>22 (17%)</td>
</tr>
<tr>
<td>1949</td>
<td>Ventilated</td>
<td>129</td>
<td>108 (84%)</td>
<td>21 (16%)</td>
</tr>
</tbody>
</table>

* Derived from Bower et al.3[1.687] † The authors point out that this figure still represents 62% of “Resp. Patients”. DOA = dead on arrival. •

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The authors stated, “Only clinical judgement or blood studies can establish the correct ventilation requirement for each patient” (p. 711) (“adequate to maintain normal levels of CO₂ and O₂ in arterial blood” (p. 710), not ventilating pressures or tidal volumes.

It is interesting to note a statement which we would now consider optimistic: “Maximum inspiration rather than maximum expiration was measured ... to prevent contamination of the working parts of the meter when used on contagious cases.” (p. 694)

Breadth of the changes at Los Angeles County Hospital

For the management of polio patients, the LACH documentation clearly demonstrates that all aspects associated with respiratory care were assessed completely, that the requirements for successful AV were determined, and that equipment redesigns were undertaken, achieved, and then applied clinically. I felt the greatest admiration for how comprehensively the problem areas were identified in a complete working system, down to the smallest levels (eg, for locking-type electric cord plugs, safety guards over the power switch); then for total respiratory care, tackled to produce the best apparatus (also the safest: it was alarmed). Measures for the comfort of patients, such as eliminating vibration and noise, were also emphasised. In this total rethink, attention to redesign extended to all equipment either already in use (eg, tracheostomy tubes, collars, all suction apparatus and mattresses) or hitherto not available; as well as to nursing practices (eg, early regular suctioning of the respiratory tree).

Such meticulous attention to detail in an acute respiratory unit during the last years of the 1940s certainly pre-dated the care we prided ourselves on for intensive care medicine when ICUs were becoming more widely established a decade later. By 1954, Bower was again referring to his Communicable Diseases Unit (p. 1) — which, by their greatly improved results in 1949, was recognisably a genuine Respiration Unit for acute polio, and deserves credit for that.

Studies and researches

In their studies, the LA team obtained “consistent and conclusive data” from 77 respirator cases, to show “consistent and significant trends” (p. 687). After carefully designing, constructing, then studying and researching the equipment in action, the authors documented “data obtained on 77 respirator cases”, and “ventilation tests . . . made on 222 patients”, (p. 693) mostly from 1949, some from back to September 1948. The studies were principally concerned with measuring the effects of numerous factors on tidal air and vital capacity. They investigated the effect of different respirators, different modes of AV, combinations and pressures of AV, different levels of paralysis and pulmonary health, etc; the results occupied 16 pages of the 1950 Part 2 article, with 27 tables and seven graphs. For instance, they found that the effect of the Trendelenburg position “on the ventilation of respirator patients” was to cause an average drop of 20% after 15 minutes.

These events took place a few years before the large-scale IPPV success of Ibsen and his team at Copenhagen, during Denmark’s 1952–53 polio epidemic. There, the Danes applied IPPV manually by bag-ventilation to a number (possibly 27711) almost fourfold more than the number of patients machine-ventilated at Los Angeles. It does not seem well known that, from the respirator cases they studied at LACH, Bower et al predated results comparable with those that Ibsen and his colleagues achieved, 1952–1953. Ibsen studied the LACH articles before 25–26 August 1952, so was aware of the Americans’ conclusions.

The LACH findings included:

- Underventilation was not uncommon with INPV (30 instances among 294 respirator cases were detected in 1948, before IPPV was introduced); and underventilation allowed CO₂ to accumulate.
- Some patients could not be ventilated adequately by INPV alone, and they always had respiratory acidosis with INPV. No cases were detected in respirator patients in 1949, once the ventilation meter was being used.
- IPPV provided better AV than did INPV; and IPPV augmented INPV.
- Administration of O₂ to underventilated patients might correct cyanosis but did not diminish CO₂ accumulation.
- For an index of ventilatory adequacy, reliance on either elevated CO₂ combining power or elevated venous plasma bicarbonate was mistaken without a simultaneous pH, as for these patients the elevations usually represented metabolic alkalosis compensatory for hypventilation.

Footnote 6. When Dr Matthew Spence appraised the unit in 1961, he commented (p. 688) “the work no longer Chief of Staff. In criticism, Matt Spence noted marked hyperventilation, uncuffed metal tracheotomy tubes, “no special respiratory regime[n]”, and was surprised that the type of artificial ventilation used for poliomyelitis, polyneuritis and tetanus was still “Combined Pressure”: (He noted curarisation was employed as needed.) There were about 20 tetanus cases annually, but “the mortality rate is disturbing at this hospital, reaching 70% in the last two years. The methods of treatment [of tetanus] are basically similar to ours [ie, Auckland's] except for the management of respiratory insufficiency”.

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Documentation

1. OldMedline lists 35 articles with A G Bower himself as first author or co-author.
2. Harold West’s 1949 article with Bower7 established their case for tracheotomy and forecast their detailed respiratory care.
3. Bower published his 1949 address to the Oregon State Medical Society, A concept of poliomyelitis based on observations and treatment of 6000 cases in a four-year period, in three parts between February and April 1950.5 Part 3 concisely provided the first documentation of the changed ventilatory methods at LACH. Only relevant to us here is Bower’s description of the process they worked through to achieve a ventilatory solution when tracheotomy alone did not correct respiratory problems.
4. Bower and V Ray Bennett, with colleagues John B Dillon and Bernard Axelrod,9n7 reported their findings at considerable length and in extensive detail in the two-part article Investigation on the care and treatment of poliomyelitis patients: Part 1 in October 19501 concerned the equipment they developed; and Part 2 in November 19502 concerned the case statistics for their clinical patients.
5. By 1954, Bower, as editor, had the LACH methods summarised in the book Diagnosis and treatment of the acute phase of poliomyelitis and its complications.4 He supplied only the first chapter (10 pages); numerous others contributed, including Elizabeth Austin (four chapters), and Clarence Dail and Seymour Cohen (two each). This was more of a how-to-do-it book and was short on details of numbers of patients treated and their survival/mortality rates.

Despite such documentation, the LA success does not appear to have yet received the level of recognition warranted. Three of Bower’s articles were quoted by Howard Howe in TM Rivers’ 1952 microbiology textbook.14 Although H C A Lassen cited one article of Bower et al, in both his 1955 WHO article15 and his 1956 book,16 each time giving guarded approval, he was more concerned to describe the equipment they developed; and Part 2 in November 19502 concerned the case statistics for their clinical patients.

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5. By 1954, Bower, as editor, had the LACH methods summarised in the book Diagnosis and treatment of the acute phase of poliomyelitis and its complications. He supplied only the first chapter (10 pages); numerous others contributed, including Elizabeth Austin (four chapters), and Clarence Dail and Seymour Cohen (two each). This was more of a how-to-do-it book and was short on details of numbers of patients treated and their survival/mortality rates.

Some puzzles

One can wonder why the pioneering work of Bower, Bennett et al at LACH, which established such a strong case for PPV, and preceded some of Ibsen’s comparable findings, is not better recognised, and referenced in its historical context. Perhaps it is because the distribution of the relatively new journal – Bower et al were writing in Volume 4 of the Annals of Western Medicine and Surgery3,3 (PubMed does not list this journal after October 1952) — was not yet wide enough to achieve that. Even so, the preceding revelatory article in Northwest Medicine2 (PubMed does not list this journal after March 1973) featured within a volume of high number (49). It is unlikely that the mass of data they published would ever have been reported with such space-occupying (and thus very expensive) detail in more highly profiled and widely circulated journals.

Nor is it at all obvious that the articles of Bowers et al were well known within the US itself. It is hardly surprising that news of Bower’s 1949 methods did not, in that same year, reach the ears of Ibsen, then a thoracic surgeon training in anaesthesia at Boston.17p281

Returning to Denmark, Ibsen, “consultant to the largest medical library in Denmark”,16p22 discovered the LACH articles at Copenhagen when “Bower and Bennett I saw in the library” (Bjorn Ibsen, personal communication, 2003). Realising that they demonstrated benefits of IPPV for severe polio, he wrote to Bower to send him a copy, before suggesting to Lassen that they introduce IPPV for the Blegdam Hospital’s polio patients. Although Lassen was unconvinced of the merits of Bower’s AV, he allowed Ibsen to go ahead with manual IPPV—with a dramatic result.9

Ibsen freely acknowledges his debt to Bower et al.9,10

Footnote 7. A G Bower carefully acknowledges his associate colleagues: Drs J Affeldt, E Austin, A Chaney, C Dail, J Chudnoff, L Fisher, W Frank, J Huntsman, E Knout, H West; and RN W Gerling, plus resident staff; also R Denton and S Cohen.4

Footnote 8. Ibsen wrote: “This I consider pioneer work in intensive therapy but only related to one disease.”17p278

FieldNote 9 (p.278)
John Powell, FRCA, points out in his website of entertaining memoirs that Bower et al did not foresee that IPPV might actually replace tank respirators altogether.23 Did lack of knowledge about the findings at Los Angeles play any role in the persistence with INPV in the US for so long into the 1950s? By contrast, after the lead from Ibsen and his colleagues,18[p.209] IPPV was quickly adopted in Europe. The Danish epidemic was over before May 1953;21 by the succeeding September, a polio victim was treated with IPPV at Oxford in the United Kingdom, with Radcliffe A & B respiration pumps,24 while another was treated at Ham Green, Bristol, UK, with James Macrae’s Clevedon respirator.23 Stock-holm, ready for the epidemic of 1953 with Engströms and other Swedish PP ventilators,25[p.63] achieved a 70% survival rate success among 89 respirator patients.23[p.111]

In summary
Greater acknowledgement should be made of the ventilatory achievements of Albert Bower and his teams in the Contagious Diseases Service at Los Angeles County General Hospital in the 1948–1949 polio epidemic. There, the first long-term, large-scale use of (supplementary) IPPV was successful. Without diminishing the tremendous credit due to Bjørn Ibsen and his colleagues, it can be pointed out that the LA pioneering, although on a smaller scale than that which took place at Copenhagen in 1952–53, did occur earlier. The marked reduction in mortality of LACH’s ventilated patients which was associated with the clinical expertise developed in the Service, together with the remarkable range of respiratory equipment and ICU-type equipment developed on-site, all testify to the excellence of the team, as can be seen in their documentation. Numerous studies, conducted in parallel with treatment, provided a scientific basis for the achievements.

I believe, based on the documentation supplied from the LACH, that these achievements place the LACH Contagious Diseases Service at the forefront of Respiration Units then established (although I have not read of such a title being claimed at LACH itself). And although the participants provided relatively complete documentation of their work, these virtues have not been widely recognised. We have the opportunity to ensure that it is done now, for the history of intensive care medicine.

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References
5 Bower AG and associates. A concept of poliomyelitis based on observations and treatment of 6,000 cases in a four-year period. Northwest Med 1950; 49: 103-7 (Part 1); 187-90 (Part 2); 261-6 (Part 3).
Appendix 1. The equipment [p.561-82][p.147-73]

Ray Bennett (now deceased) was already famous from World War II days for his BR-X2 resuscitator, which provided intermittent breaths of high pressure oxygen for pilots in unpressurised aircraft in high altitude research.\(^\text{18}\) He developed a flow-sensitive valve for the resuscitator in 1944. His mobile BR-X2 resuscitator for emergency intermittent positive pressure ventilation of any degree required time-cycled use; for long term use, it was less practical than a respirator.

After the War, Bennett’s attention to the problems of ventilated polio patients at Los Angeles County Hospital resulted in the following developments:

- The (Bennett) positive pressure respirator attachment (BPPRA), which was used with a mask, or with Bower’s adaptor to a tracheotomy tube.
- The humidifier attachment for the BPPRA, which supplied 80% relative humidity (but at room temperature).
- The respiratory ventilation meter which gave > 95% accuracy and was used in all the 1949–1950 ventilatory studies.
- The (Bennett) flow-sensitive pressure breathing unit, which was in clinical use for several years before 1948.
- A physiological cam for the respirator, which increased ventilatory depth and patient comfort for a lesser negative pressure applied by a Drinker. It could be made to produce almost any pressure pattern.
- A mobile, motorised unit (a BPPRA unit in a cabinet), which was not flow-sensitive and provided fixed cycle intermittent positive pressure ventilation.\(^\text{1p.572}\) This was connected in “selected cases” only (as it was unsuitable for long-term use), via a mask or preferably an adaptor to a tracheotomy tube.
- An oxygen cylinder warning signal device, which sounded at 10 minutes residual O\(_2\).
- A respirator-pressure warning signal, which flashed red and was “designed to be as foolproof as possible”.
- An air-pressureising unit (electrical) to supply filtered air for the (Bennett) flow-sensitive pressure breathing unit.
- Other instrumentation advances:
  - Improved respirator collar;
  - Improved tracheotomy tubes, adaptors and accessories;
  - Improved suctioning equipment;
  - Positive pressure adaptor for bronchoscoped patients;
  - O\(_2\) catheter for tracheotomy tubes; and
  - New smaller-celled pulsating pneumatic respirator mattress.
- Multiple miscellaneous “developmental” improvements in the respirator itself.\(^\text{1p.582}\)

In 1956, V Ray Bennett and Associates Inc was acquired by the Puritan Compressed Gas Corporation (which originated in the Parker & Francis Company of 1913), hence the name Puritan–Bennett Corporation.

Appendix 2. For physiological researches, Bower et al used the following \(^\text{1p.688}\)

- A femoral arterial line (indwelling) for sampling, usually in duplicate.
- Two laboratories cross-checking results.
- Arterial O\(_2\) saturation per (Van Slyke method of) vols % (whole blood).
- Assessment of respiratory acidosis from:
  - pH per a Beckman meter, with
  - “CO\(_2\) values” by two different laboratory methods:
    i. (Van Slyke method of) total CO\(_2\), or
    ii. after removal of CO\(_2\) from plasma, back-titration to original pH gave bicarbonate vols % of plasma.

(This method of assessing respiratory acidosis anticipated the Blegdam method, post-27 August 1952. Before that HCA Lassen was determining only total CO\(_2\) content, as the only pH electrodes available to him were too large for practical use until Poul Astrup acquired Radiometer’s pH mini-electrode.\(^\text{9,10}\))

- By 1954, oximeters and infra-red analysers for CO\(_2\) were being used.