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Intraabdominal Surgery and Anesthesia Management

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Inspired Oxygenation in Surgical Patients During General Anesthesia With Controlled Ventilation: A Concept of Atelectasis. By Bendixen HH, Hedley-Whyte J, and Laver MB. *New Engl J Med* 1963; 269:991–996. Reprinted with permission.

Abstract: The purpose of this study was to determine if the pattern of ventilation, by itself, influences oxygenation during anesthesia and surgery and examine the hypothesis that progressive pulmonary atelectasis may occur during constant ventilation whenever periodic hyperventilation is lacking, but is reversible by passive hyperinflation of the lungs. Eighteen surgical patients, ranging in age from 24 to 87 yr, without known pulmonary disease, were studied during intraabdominal procedures and one radical mastectomy.

Although ventilation remained constant, changes occurred in arterial oxygen tension and in total pulmonary compliance, with an average fall of 22% in oxygen tension and 15% in total pulmonary compliance. This fall in oxygen tension supports the hypothesis that progressive mechanical atelectasis may lead to increased venous admixture to arterial blood. The influence of the ventilator pattern on atelectasis and shunting is further illustrated by the reversibility of the fall in oxygen tension that follows hyperinflation. A relation between the degree of ventilation and the magnitude of fall in arterial oxygen tension was found, where large tidal volumes appear to protect against falls in oxygen tension, while shallow tidal volumes lead to atelectasis and increased shunting with impaired oxygenation.

RESPIRATORY failure is a common complication of abdominal surgery. Early investigations by Professor Edward D. Churchill and his student Henry K. Beecher identified this problem. In 1933, medical student Henry K. Beecher from Professor Edward D. Churchill's Harvard Department of Surgery at the Massachusetts General Hospital, Boston, Massachusetts, wrote two articles.^{1,2} These articles confirmed and expanded Dr. Churchill's own 1927 work on the deleterious effect of laparotomy and anesthesia in lung conformation and function in human patients.³

Edward D. (Pete) Churchill, M.D., was a superb department head. His background included being Chief Surgical

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Consultant to the North African and Mediterranean Theater of the Allies in World War II.⁴ He had successfully treated President Franklin D. Roosevelt's son's pneumonic hypoxemia. Dr. Churchill raised funding from the National Institutes of Health Heart Institute for our study now being revisited,⁵ and wished to have the same anesthetist throughout the study. I subsequently learned that he questioned his Mediterranean Theater colleague, Sir Clifford Naunton Morgan, M.S., F.R.C.S. (Eng),⁶ about my collaboration; the latter replied, "Most of the time Hedley will do what we tell him." Dr. Churchill initiated and led our study⁵ and commented, as did Henry K. Beecher, M.D., on the drafts we submitted to the *New England Journal of Medicine*. Both Drs. Beecher and Churchill declined coauthorships: "That is not our style," they both said to us, infinitely their juniors.

I had spent 1958 to 1960 as House Surgeon and Resident Anesthetist and Chief Resident to Sir Clifford Naunton Morgan, the leading abdominal surgeon at St. Bartholomew's Hospital and Medical School in London, United Kingdom.⁶ Previous to that, from 1952 to 1955, my tutor at Clare College, University of Cambridge, Cambridge, United Kingdom, was Sir Michael P. Stoker, the first British professor of virology.⁷

In 1961, I had been appointed Assistant in Dr. Churchill's Department of Surgery.⁴ Henrik H. Bendixen, M.D., self-appointed as my research mentor, had served on a Danish Hospital Ship during the Korean War, and like Drs. Beecher and Churchill, had been trained in lung oxygen passage by the research of Drs. August and Marie Krogh and Christian Bohr in Copenhagen.^{8–10}

Drs. Beecher and Churchill had recruited Myron B. Laver, M.D., from the University of Basel, Basel, Switzerland, to which he later returned as Professor and Chair of Anesthesia.¹¹ In 1961, Dr. Laver was given the role of setting up and perfecting our Blood Gas Laboratory, located one floor above the main operating rooms (ORs) of the Massachusetts General Hospital—an innovation crucial to the successful conduct of our study. Financial support for developing this facility was provided, at generous levels, by patients and philanthropy.¹² Intellectual, practical, and engineering advice was provided by John R. Pappenheimer, Ph.D.¹³ and Plummer Chair of Colloid Science at the University of Cambridge, Francis John Worsley Roughton, Fellow of the Royal Society (1936).¹⁴ In 1937, while Lecturer in Physiology at the University of Cambridge, Roughton had recruited Dr. Pappenheimer from Woods Hole Marine Biological Laboratory to Clare College, University of Cambridge, to be in residence for 3 yr and acquire, after a thesis defense, a Ph.D.¹³ In 1940, F.J.W. Roughton was, in turn, recruited to the Harvard Fatigue Laboratory to conduct war-related research on the respiratory effects of carbon monoxide. Dr. Pappenheimer worked and perfected on demand and automatic oxygen flushes for hypoxemic pilots of Spitfires and Hurricanes—a not-inconsiderable contribution to victory in the Battle of Britain in 1940.¹⁵ He then was required to

return to the United States where he held war-time positions at Columbia University, New York, New York, and the University of Pennsylvania, Philadelphia, Pennsylvania, before being called to Harvard University, Cambridge, Massachusetts, in 1946. U.S. patent requests were later denied to the developers of blood gas electrodes employing semipermeable membranes because of previous use of the methodology by John R. Pappenheimer, Higginson Professor of Physiology, Harvard University.^{13,16}

I was the anesthesiologist assigned to our study,⁵ which began when surgery was in process. Arterial blood samples were taken every 10 to 30 min. The mean duration of the study periods of constant ventilation was 76 min, ranging from 30 to 165 min. A dedicated messenger transported promptly, and at the temperature of the patient, blood samples to Dr. Laver's Blood Gas Laboratory on the floor above. Modified Clark electrodes were used.⁵ Samples were in duplicate. Dr. Bendixen gave deep breaths with C. D. Janney's Super-Syringe.¹⁷ Robert Linton, M.D., was appointed backup surgeon for the study.^{18,19} Michael Stoker, M.D., advised as to management of viremia.⁷ We had no complications in these studies, but contemporaneously in a nonstudy patient, Dr. Linton had to extract from the superior vena cava of an obese woman a transected venous catheter that I had placed in her right arm.

Ages of the 18 patients ranged from 24 to 87 yr, with average age 59 yr. Premedication was with 1 mg intramuscular pentobarbital sodium for 0.7 kg body weight and 0.6 mg atropine sulfate. Tracheal cuffs were inflated. Nine patients were maintained with halothane at approximately 1% in pure oxygen. The other nine patients were administered nitrous oxide in ratios ranging from 4:1 oxygen to 2:1. Intravenous D-tubocurarine was given in divided doses to maintain profound relaxation throughout the surgical procedure. Total gas flow ranged from 6 to 10 l/min. Ventilation was controlled by using mechanical respirators (pressure regulated), always at a frequency of 20 to 25 breaths/min.⁵

Professor Churchill and matron of the ORs Helen Coghlan^{20,21} took a great interest in our initial study of 17 abdominal operations and one mastectomy.⁵ They could and did observe our ORs from the floor above. Woe betide the medical student, nurse, or surgeon who was leaning on a patient's chest or less than optimally holding a retractor. Everyone knew of Matron Coghlan's having frog-marched General George S. Patton, Jr., out of 'her' 93rd Evacuation Hospital in Sicily.^{20,22}

The results of our study⁵ showed that ventilation of our subjects varied from "moderate hypoventilation to outright hyperventilation", while ventilation of each individual remained constant throughout, as shown by arterial pH and carbon dioxide tension. At the same time, there were changes in arterial oxygen tension and total pulmonary compliance, with an average fall of 22% and 15% respectively, again, with considerable variation between cases. Decreased oxygen tension showed linear relation to the degree of ventilation, as

defined by the mean arterial tension of carbon dioxide. We demonstrated that in patients with hyperventilation, the fall in oxygen tension was small, but this drop was significant in patients with normal or subnormal ventilation, *i.e.*, high carbon dioxide tension. Postre-inflation, oxygen tension, and compliance returned to near prestudy levels (fig. 1). Our results supported the hypothesis that progressive mechanical atelectasis may, by shunting, lead to increased venous admixture to arterial blood. The reversibility of the decrease in oxygen tension after hyperinflation supports the influence of the ventilatory pattern on atelectasis and shunting and provides evidence that atelectatic alveoli are reopened by a deep breath. The magnitude of the fall in oxygen tension is of clinical importance. Normal patients take periodic deep breaths, which limit progressive alveolar collapse. Both during and after surgery and anesthesia increased shunting occurs; the provision of continuous large tidal volumes or periodic deep breaths (hyperinflations) aids in preventing an increase in the variable shunt, *i.e.*, atelectasis. The high incidence of atelectasis and pneumonia in patients after thoracic and abdominal surgeries is, in part, the result of surgical sequelae such as incisional pain, prolonged effect of anesthetics, and certain positions that may limit the adequate expansion of the lungs to provide the postsurgical benefits of deep breaths. These

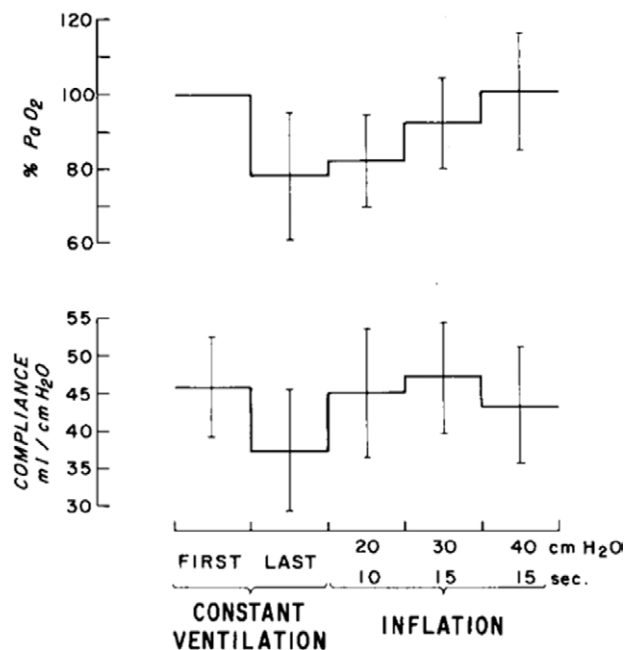


Fig. 1. Alveolar falls (with SDs) in oxygen tension (expressed in percent) and in total lung compliance as the difference between first and last measurements during constant ventilation. Three successive inflations restore previous levels of compliance (with the first inflation) and oxygen tension (in steps). Reprinted with permission from Bendixen HH, Hedley-Whyte J, Laver MB: Impaired oxygenation in surgical patients during general anesthesia with controlled ventilation: A concept of atelectasis. *New Engl J Med* 1963; 269:991-6. Copyright © 1963 Massachusetts Medical Society.

findings led to innovations in the intensive care unit and the advanced training of specialized personnel.²³

Why the improvement in the results and course of human abdominal surgery from the 1960s to the 1970s and 1980s? The vulnerability of postoperative patients to pulmonary alveolar collapse and resultant hypoxemia and superinfection in the atelectatic area of the lung was recognized. Technological advances and innovations in information transfer, the widespread availability of intensive care units, and improved training of personnel in increased numbers led to improved patient outcomes.²³

What, over the next half century, did people think of the article? It is hard to tell. Judging by citations rates (Supplemental fig. 1A, <http://links.lww.com/ALN/B328>), some people seem to have read and still read the 1963 article. Possibly, some readers have extrapolated too far from this limited study of 17 abdominal surgeries carried out in late 1961 and early 1962.

Our original work was followed by further investigation on morbidity and mortality of abdominal surgery. In 1969 during an 8-month period, 396 of our patients had abdominal operations (exclusive of pelvic laparotomy): 58 were admitted to our Respiratory Surgical Intensive Care Unit. Of these, 29 had to be treated for respiratory failure greater than 24 h. Eighty-six percent of patients with respiratory failure but without peritonitis survived, but four of five with peritonitis died (Supplemental fig. 1B, <http://links.lww.com/ALN/B328>).²⁴

Our 1979 *JAMA* article describes our surgical treatment of 500 consecutive patients more than 80 yr of age.²⁵ Twenty-four percent of 141 patients who underwent upper abdominal surgery required artificial ventilation postoperatively for more than 24 h. Six patients died of mesenteric infarction. Hospital mortality was 6% within 1 month of surgery (Supplemental fig. 1C, <http://links.lww.com/ALN/B328>).²⁵

Our 1982 *Lancet* article found that in 87% of 60 consecutive patients, after antacid therapy, one or more organisms were cultured simultaneously from both upper airway and stomach (Supplemental fig. 1D, <http://links.lww.com/ALN/B328>).²⁶ William Silen, M.D., we stated, was responsible for overseeing the standards of surgical care. In 1967, Dr. Silen, as he recounts in his Preface to the current 22nd edition, took over from Sir Zachary Cope (1881 to 1974) maintenance and revision of *Cope's Early Diagnosis of the Acute Abdomen*.²⁷ The encomium on Silen's winning the Julius Friedenwald Medal of the American Gastroenterological Association for lifelong contributions to clinical practice, teaching, and research in gastroenterology describes the qualities needed for optimal management of abdominal surgery: these qualities we achieved and taught.²⁸

Drs. Beecher, Churchill, Hedley-Whyte, and Linton now have eponymous professorships at Harvard University. The late Dr. Bendixen has two eponymous professorships at Columbia University, New York, New York; his daughter

Birgitte Bendixen, M.D., Ph.D., a distinguished neurologist at the Albert Einstein College of Medicine, died in 2011.²⁹ Dr. Stoker was knighted by Elizabeth II on December 2, 1980,³⁰ having been elected Fellow of the Royal Society, the independent scientific academy of the United Kingdom and the Commonwealth, in 1968.¹³

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Address correspondence to Dr. Hedley-Whyte: David S. Sheridan Professorship in Anaesthesia and Respiratory Therapy, Harvard University, 1400 VFW Parkway, Boston, Massachusetts 02132. john_hedley-whyte@hms.harvard.edu. Information on purchasing reprints may be found at www.anesthesiology.org or on the masthead page at the beginning of this issue. ANESTHESIOLOGY's articles are made freely accessible to all readers, for personal use only, 6 months from the cover date of the issue.

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