Can J Anesth/J Can Anesth (2014) 61:383–386
DOI 10.1007/s12630-013-0098-1

SPECIAL ARTICLE

From the *Journal* archives: Airway closure and lung volumes in surgical positions

Hilary P. Grocott, MD

Received: 8 August 2013 / Accepted: 11 December 2013 / Published online: 18 January 2014

Editor's Note: Classics Revisited

Key Articles from the *Canadian Journal of Anesthesia* Archives: 1954-2013

As part of the *Journal's* 60th anniversary Diamond Jubilee Celebration, a number of seminal articles from the *Journal* archives are highlighted in the *Journal's* 61st printed volume and online at: www.springer.com/12630. The following article was selected on the basis of its novelty at the time of publication, its scientific merit, and its overall importance to clinical practice: *Craig DB, Wahba WM, Don H.* Airway closure and lung volumes in surgical positions. Can Anaesth Soc J 1971; 18: 92-9. Dr. Hilary P. Grocott provides expert commentary on this work published in the *Journal* more than 40 years ago, that is seminal to our understanding of how patient positioning influences lung volumes, and how age influences the relationship between functional residual capacity and closing volumes.

Donald R. Miller MD, Former Editor-in-Chief

Summary

Authors *Douglas B. Craig, W.M. Wahba, Hillary Don*

Citation *Can Anaesth Soc J 1971; 18: 92-9.*

Purpose *Surgery and anesthesia expose patients to moderate and sometimes extreme positioning changes that are often unphysiological. The purpose of this article is to highlight and contextualize a seminal study from the Journal archives that explores the effect of several commonly utilized surgical positions (supine, Trendelenburg and lithotomy) and age on basic lung volumes as well as the volume at which small airway closure (AC) (also known as closing volume [CV]) occurs. These factors were examined with the aim of determining which patient position variables could be of clinical significance to gas exchange in the perioperative period.*

Principal findings *This work showed that supine positioning, when compared with the seated position, results in a decrease of all lung volumes and capacities, including functional residual capacity (FRC) and CV. Trendelenburg positioning further decreases FRC, with no further changes induced by lithotomy positioning. Age is a clinically important factor in AC, occurring within the tidal volume range at a lower age when supine as compared with the seated position.*

Conclusions *The work of Drs. D. Craig et al. published in the Journal more than 40 years ago was seminal to our understanding of how patient positioning has an important influence on lung volumes and on the age-related relationship between FRC and CV.*

In keeping with the *Canadian Journal of Anesthesia's* 60th anniversary celebration in 2014, we highlight this seminal paper from Craig *et al.*[1] as one of the classic articles from the *Journal* archives representing pivotal work in the field of perioperative respiratory physiology. A number of pertinent issues are addressed in this commentary. The historical context of the article allows better appreciation of

H. P. Grocott, MD (✉)
Departments of Anesthesia & Perioperative Medicine and Surgery, St. Boniface Hospital, University of Manitoba, CR3008 - 369 Tache Avenue, Winnipeg, MB R2H 2A6, Canada
e-mail: hgrocott@sbgh.mb.ca

the knowledge gaps that existed at the time the study was performed and of the contribution this publication made to our better understanding of these knowledge gaps. This commentary also revisits the original story to show how the findings related to changes in patient positioning and age and their impact on lung volumes remain relevant in the current practice of anesthesia. Importantly, although this was relatively novel information when it appeared in the anesthesia literature, it was also part of a larger body of investigative work undertaken by these investigators (and others) during a period of intense knowledge generation in applied respiratory physiology. In addition to revisiting the science (including direct insights from personal communications with Dr. Craig), the reader is given a *behind the scenes* perspective on when, where, how, and on whom these experiments were performed as well as consideration of the labour-intensive nature of manuscript preparation and submission before the age of computers and modern day word processors. Lastly, in the context of the increasing (and justifiably important) focus on ethics in research and academic medicine (and publishing), not to mention the growing number of articles that have been retracted for scientific ethical misconduct,[2] perspectives on the research ethics approval process (or relative lack thereof) existing at the time of this study are considered very briefly.

Airway closure (AC) was a fundamental discovery to the understanding of factors that could result in perioperative atelectasis and subsequent ventilation-perfusion (V/Q) mismatch. The concept of AC developed in the late 1960s and was conceived to explain why gravity-dependent areas of the lung ceased emptying during late expiration in the vital capacity respiratory cycle. Leblanc *et al.* first highlighted the importance of body position. In addition to showing the adverse effects of age, they highlighted the impact of body position (i.e., seated *vs* supine) on AC as well as other lung volumes, with the impact on functional residual capacity (FRC) being most significant.[3] Prior to the extension of these ideas by Craig *et al*., anesthesiologists had yet to consider these issues, although they were being reported in some detail in the respiratory physiology literature.[4] These concepts were subsequently shown to have major functional significance for patients undergoing anesthesia. Indeed, in some respects, the paper by Craig *et al.* was a revisiting of the initial Leblanc study but with the additional pertinent surgical positions of both Trendelenburg and lithotomy.

The interaction of age on lung volumes was also examined in this study. The relevance of these age-related effects in some respects pre-dates the current intense focus on the effects of aging on anesthetic management.[5] It is historically interesting that the impact of "age" in this study was inferred by examining subjects who were all relatively "young" by today's standards (i.e., age 28-53 yr).

As is often the case, the importance of the broader scientific body of literature at the time is often not appreciated when a publication is read in isolation of the context in which it was generated. Indeed, the other peripheral papers are arguably even more important than the Craig *et al.* paper which is the focus of this commentary. For example, their study took place at a time when a great deal of work was being performed in respiratory physiology,[4] but not necessarily in the perioperative setting. This present paper reports results of a small part of a larger research program that was subsequently published in the *Journal of Applied Physiology*,[6] where gas exchange and invasive measures of cardiac output were examined in addition to AC (and its relationship to FRC). As a result, although Craig *et al.* report an interesting and very pertinent finding in this paper, it is somewhat of an isolated fact that needs to be considered within the bigger picture that existed at the time. Indeed, in Dr. Craig's own words, publication of his paper in the *Canadian Anaesthetists' Society Journal* was a relatively minor "side issue" of more major investigations that continued in the early 1970s.[7]

Although this paper may have been considered a side issue by its principal author, it is one that has had considerable longevity and importance despite the humility of its first author. We now take for granted that significant respiratory changes occur with body positions assumed for surgery. Trainees in anesthesia should be well versed in these aspects, particularly as they prepare for their Royal College examinations.

The long-lasting impact of this early work can be seen in the large number of research reports that followed, in part, as a consequence of their earlier work. Multiple examples of the impact of airway closure can be seen in the anesthesia, critical care, and even sleep apnea literature.[8,9] It is fundamental to our understanding of perioperative atelectasis and V/Q mismatch. As a particularly germane example, pre-oxygenation prior to the induction of anesthesia can exploit the physiological mechanism described by Craig *et al*. in their early work, particularly in those with respiratory physiology compromised by obesity.[10-12] In the non-obese, Lane *et al*. have recently reported that a 20° head-up position maintained during pre-oxygenation can significantly delay the onset of desaturation during anesthesia induction, likely a direct consequence of reducing AC during these tidal volume breaths.[13] My own personal observations in the operating room of colleagues and trainees suggest that, surprisingly, this elevation of the back during pre-oxygenation is used less frequently than it could be; it can be easily justified by these earlier studies.[14]

The importance of this paper at the time (if not because of its novelty) was highlighted as anesthesiologists and readers of the *Journal* became increasingly aware of the importance of AC and the impact of surgical positioning. Interestingly, for their work on this study, Dr. Craig and his co-author's, Drs. Wahba and Don, received the 1971 Canadian Anesthesiologists' Society prize for *Best Original Work in Anesthesia performed in Canada* (an award no longer offered at the Society's annual meeting). It was recognized then, as it is now, as an important part of anesthesia *Canadiana*. Research funding was an issue then, as it is now; Dr. Craig was funded for this work by the legacy Medical Research Council of Canada (now the Canadian Institutes of Health Research). Furthermore, this investigative work, of which this paper was a part, formed the basis for his master's thesis awarded by McGill University in 1970.

The study itself was carried out in the Meakins-Christie Laboratory for Respiratory Research at McGill University. The work in this lab was highly focused on cutting-edge understanding of respiratory physiology, including lung mechanics and airway dynamics. The technique utilized in the lab was known as the modified single-breath nitrogen technique. After exhaling to residual volume (RV), research subjects were switched to an oxygen-filled closed breathing circuit system and then inspired a vital capacity breath. After a ten-second breath hold, they slowly exhaled while the expired gas was sampled at the mouth for nitrogen (N_2). The N_2 concentration in the expired gas is measured as a function of expired volume with the tracing divided into four phases: the N_2-free dead space (Phase I), the transition from dead space to alveolar gas (Phase II), an alveolar plateau characterized by cardiac oscillations (Phase III), and the rising slope (Phase IV) of expired N_2, with the inflection point defining closing volume (Figure).

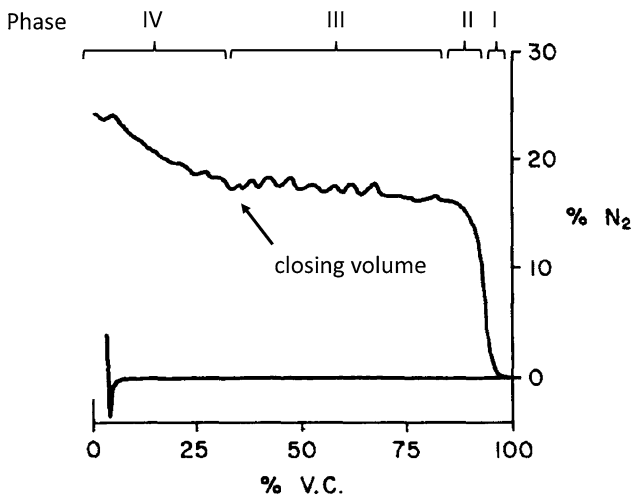

Figure A modified single-breath nitrogen technique used to determine closing volume. The concentration of nitrogen (N_2) is measured at the mouth as a function of expired volume, in percent vital capacity (VC). Modified and reprinted with permission from *Craig DB, Wahba WM, Don H.* Airway closure and lung volumes in surgical positions. Can Anaesth Soc J 1971; 18: 92-9

The abrupt increase in N_2 at the start of Phase IV can be explained as follows. After breathing room air and expiring to RV, the subsequent 100% O_2 vital capacity (VC) breath creates a top to bottom gradient in alveolar N_2 concentration. Although the size of lung units at total lung capacity is similar top to bottom, with expiration to RV, the upper units are larger and therefore contain more N_2. With the VC O_2 breath, the smaller lower units receive more volume than those at the top. Accordingly, the N_2 in the lower units gets more diluted with O_2 than those at the top. During VC expiration, when the low N_2 lower lung units stop emptying, the upper units rich in N_2 continue to empty, thus leading to the rising slope of Phase IV.

As is often the case, a study such as this could not have been undertaken without substantive advice from Meakins-Christie Laboratory faculty members as well as expert assistance from laboratory technical staff. This approach is similar to the way studies are often undertaken today; these technicians are often the unsung heroes behind the scenes in some of these studies. The research technicians (as well as statisticians) provide much needed detail, but are often lost behind the headlines.

As part of the *story behind the story*, it is interesting to point out that the "volunteers" ($n = 10$) in the study were the physician investigators themselves along with several McGill anesthesia residents. There was no mention in the paper of any research review board/ethics committee approval, though a process for institutional review was in place. Accordingly, the consent process was verbal only and very informal at that. Furthermore, the authors availed themselves not only to participate as research subjects in these investigations, but also to do so without consideration for some of the potential risks involved. Though not in this particular study *per se*, in their other published studies from the larger perioperative respiratory physiology research program, the study subjects were subjected to central venous cannulation for an injection of indocyanine green (allowing for cardiac output measurements), though this procedure itself was preceded by written consent.[6]

These studies were also performed at a time when privacy concerns were less at the forefront. Today's provincial legislatures have put detailed policies in place that are intended to protect personal health information. These privacy protections have a wide-ranging impact on research technique and infrastructure. Indeed, enormous efforts are made to ensure the general protection of research subjects. This process has evolved considerably over the decades with the introduction of specific universal

policies to ensure that the privacy of research subjects is maintained. Interestingly, an astute reader could easily identify the research subjects in the original publication by their printed initials. Clearly, this would not be allowable by today's ethical research and publication standards.

In summary, this paper provided important insights into the effects of commonly used surgical positions superimposed on the effects of aging. It is information that is easily taken for granted but fundamental to our understanding of perioperative respiratory physiology. These early studies on the physiologic significance of patient positioning are increasingly relevant today with the extremes of positioning (such as steep Trendelenburg for prostatic and gynecologic surgery) and patient age.[15] This paper deservedly belongs in the archives, not just for its importance at the time, but for its continued relevance to the practice of anesthesia today.

Key points

- All lung volumes, including functional residual capacity (FRC) and the volume at which airway closure occurs (also known as the closing volume [CV]) are reduced by moving from the seated to the supine position.
- Further reductions in most lung volumes (except CV) are seen with Trendelenburg positioning.
- When CV occurs in the range of the tidal volume (V_T), significant ventilation-perfusion (V/Q) mismatch can occur.
- Age negatively impacts the FRC/CV relationship.
- Compared with sitting, supine positioning results in the CV occurring within the V_T at a younger age, thereby defined as the *critical age*.
- Minimizing duration of supine positioning may reduce perioperative hypoxemia by avoiding its adverse V/Q changes.

Acknowledgement I am indebted to Dr. Doug Craig for making himself readily available for personal interviews aimed at increasing my depth of understanding of his original work. Furthermore, Dr. Craig provided editorial review during manuscript preparation.

Funding sources Internal departmental funding.

Conflicts of interest None declared.

References

1. *Craig DB*, *Wahba WM*, *Don H*. Airway closure and lung volumes in surgical positions. Can Anaesth Soc J 1971; 18: 92-9.
2. *Miller DR*. Retraction of articles written by Dr. Yoshitaka Fujii. Can J Anesth 2012; 59: 1081-8.
3. *Leblanc P*, *Ruff F*, *Milic-Emili J*. Effects of age and body position on "airway closure" in man. J Appl Physiol 1970; 28: 448-51.
4. *Anthonisen NR*, *Danson J*, *Robertson PC*, *Ross WR*. Airway closure as a function of age. Respir Physiol 1969; 8: 58-65.
5. *Deiner S*, *Silverstein JH*. Anesthesia for geriatric patients. Minerva Anestesiol 2011; 77: 180-9.
6. *Craig DB*, *Wahba WM*, *Don HF*, *Couture JG*, *Becklake MR*. "Closing volume" and its relationship to gas exchange in seated and supine positions. J Appl Physiol 1971; 31: 717-21.
7. *Don HF*, *Wahba WM*, *Craig DB*. Airway closure, gas trapping, and the functional residual capacity during anesthesia. Anesthesiology 1972; 36: 533-9.
8. *Wahba RM*. Airway closure and intraoperative hypoxaemia: twenty-five years later. Can J Anaesth 1996; 43: 1144-9.
9. *Hakala K*, *Maasilta P*, *Sovijarvi AR*. Upright body position and weight loss improve respiratory mechanics and daytime oxygenation in obese patients with obstructive sleep apnoea. Clin Physiol 2000; 20: 50-5.
10. *Dixon BJ*, *Dixon JB*, *Carden JR*, *et al*. Preoxygenation is more effective in the 25 degrees head-up position than in the supine position in severely obese patients: a randomized controlled study. Anesthesiology 2005; 102: 1110-5.
11. *Cullen A*, *Ferguson A*. Perioperative management of the severely obese patient: a selective pathophysiological review. Can J Anesth 2012; 59: 974-96.
12. *Murphy C*, *Wong DT*. Airway management and oxygenation in obese patients. Can J Anesth 2013; 60: 929-45.
13. *Lane S*, *Saunders D*, *Schofield A*, *Padmanabhan R*, *Hildreth A*, *Laws D*. A prospective, randomised controlled trial comparing the efficacy of pre-oxygenation in the 20 degrees head-up vs supine position. Anaesthesia 2005; 60: 1064-7.
14. *Tanoubi I*, *Drolet P*, *Donati F*. Optimizing preoxygenation in adults. Can J Anesth 2009; 56: 449-66.
15. *Drummond GB*, *Martin LV*. Pressure-volume relationships in the lung during laparoscopy. Br J Anaesth 1978; 50: 261-70.