Review article: Age related alterations in respiratory function - anesthetic considerations

[Article de synthèse : Les modifications de fonction respiratoire liées à l'âge – considérations anesthésiques]

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Purpose: This review examines the effect of aging on pulmonary reserve. Special emphasis is placed on how anesthetic and surgical factors may impose substantial stresses on the respiratory system of elderly patients, leading to increased risk for postoperative pulmonary complications including respiratory failure.

Source: A MEDLINE-based English-language literature search was undertaken for the period 1966–2006, and an EMBASE search covered the overlapping period 1988–2006. Selected articles were limited to those applying to elderly subjects/patients.

Principal findings: Age-related loss of the lung static recoil forces, stiffening of the chest wall and diminished alveolar surface area lead to a decrease in vital capacity, an increase in residual volume, decrease in expiratory flows and increased ventilation-perfusion heterogeneity. Respiratory muscle strength consistently declines with age further increasing the work of breathing. While gas exchange may be well preserved at rest and during exertion, pulmonary reserve is diminished, and under conditions of positive fluid balance, positioning for surgery, and increased metabolic demand, postoperative respiratory failure can occur. Increased sensitivity to respiratory depressants and muscle weakness pose additional risks for the development of postoperative respiratory complications in elderly patients. Regional anesthetic techniques provide for superior postoperative analgesia, without necessarily altering the frequency of postoperative pulmonary complications in the older surgical population.

Conclusion: Alterations in respiratory physiology associated with aging must be appreciated to anticipate and minimize potential complications associated with surgery and anesthesia in the elderly. Individualized care to optimize preoperative cardiorespiratory function, minimize intraoperative respiratory pertubations, and to gently restore postoperative pulmonary function are essential anesthetic goals for elderly patients who require surgery.

***Objectif** : Cet article traite de l'effet du vieillissement sur la réserve pulmonaire. En particulier, on se tourne vers les facteurs anesthésiques et chirurgicaux qui imposent un stress substantiel sur le système respiratoire des patients âgés, en les mettant à risque de complications respiratoires postopératoires, dont l'insuffisance respiratoire.*

***Source** : Une recherche des articles publiés en langue anglaise de 1966 à 2006 a été entreprise en se servant de MEDLINE. La période 1988–2006 a aussi été fouillée avec EMBASE. On a sélectionné que les articles portant sur les patients ou sujets âgés.*

***Constatations principales** : Avec l'âge, l'atténuation de la force statique de recul des poumons, la rigidité de la cage thoracique et la diminution de la surface des alvéoles produit une réduction de la capacité vitale, une augmentation du volume résiduel, une diminution des débits expiratoires et une plus grande inadéquation ventilation-perfusion. La force des muscles respiratoires diminue constamment avec l'âge, ce qui augmente le travail respiratoire. L'échange gazeux est normal au repos et pendant l'exercice, mais la réserve pulmonaire est diminuée. Ainsi, avec une surcharge liquidienne, un positionnement pour la chirurgie et une demande métabolique accrue, une insuffisance respiratoire peut survenir en période postopératoire. Les patients âgés sont plus sensibles aux médicaments qui dépriment la respiration et leurs muscles sont plus faibles, d'où un risque augmenté de complications respiratoires postopératoires. Les techniques d'anesthésie loco-régionales produisent une analgésie postopératoire de qualité, sans toujours modifier l'incidence de complications pulmonaires postopératoires chez les sujets âgés.*

***Conclusion** : On doit tenir compte des changements physiologiques respiratoires découlant du vieillissement pour prévoir et atténuer les complications qui peuvent survenir suite à une chirurgie et une anesthésie chez les sujets âgés. L'anesthésiologiste doit viser un traitement individualisé pour optimiser la fonction cardiorespiratoire avant la chirurgie, limiter l'atteinte respiratoire pendant la chirurgie et assurer une récupération en douceur de la fonction pulmonaire en postopératoire.*

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Support provided by the Department of Anesthesiology, Mayo Clinic, Rochester, MN, USA.

Accepted for publication July 21, 2006.

Revision accepted September 12, 2006.

THE lungs continue to develop throughout life, with maximal functional status achieved in the early part of the third decade.[1] Lung function gradually declines thereafter, even in athletes who attempt to maintain aerobic capacity.[2,3] Aging is associated with multiple changes in respiratory physiology, including structural changes in both the lungs and chest wall leading to alteration in measurable mechanical properties of respiratory system, reduction of arterial oxyhemoglobin saturation, and impaired response to hypoxia (Table I).

Understanding the effects of aging on respiratory function is important to anticipate potential problems that may result from reduced respiratory reserve. Inadequacy of respiratory function may become particularly relevant in the perioperative period when numerous anesthetic and surgical factors may impose additional burdens on elderly patients with diminished pulmonary reserve. These factors include body positioning, residual effects of anesthetics on control of respiration, structural and functional disruption of respiratory muscles, and perioperative changes in lung fluid balance. The interaction of these factors with the aging respiratory system has considerable clinical significance: postoperative respiratory complications account for approximately 40% of the perioperative deaths in patients over 65 yr of age.[4]

This review will describe the fundamental changes in respiratory structure and function associated with aging, and how these changes may affect the perioperative course of elderly patients. A MEDLINE-based English-language literature search was undertaken for the period 1966–2006, and an EMBASE search covered the overlapping period 1988–2006. The initial search was performed using the following keywords and terms: "pulmonary function", "surgery", "geriatric an(a)esthesia", "anesthetic agents", "respiratory insufficiency", "respiratory failure", "airway resistance", "respiratory system (lung, chest wall) compliance", "perioperative period", "intraoperative complications", and "perioperative care". Bibliographies of retrieved publications were scanned for additional sources, and selected articles were limited to those applying to elderly subjects/patients.

AGE-RELATED CHANGES IN PULMONARY FUNCTION

Structural basis for changes in pulmonary mechanics

Lung parenchyma

With aging, structural alterations in the lung parenchyma occur such that there is a gradual reduction in lung elastic recoil, the inward force that promotes decreases in lung volume, at an average rate between 0.1 and 0.2 cm H_2O per year.[5] Factors contributing to this reduction include changes in the spatial arrangement and/or cross-linking of the elastic fibre network.[6] This becomes more pronounced after 50 yr of age, and may result in a homogenous enlargement of air-spaces causing the reduction of alveolar surface area from 75 m^2 at age 30 to 60 m^2 at age 70.[6] Although histologically these changes are not associated with evidence of destruction of alveolar walls, they functionally resemble emphysema.[7,8] This loss of parenchymal elasticity with aging increases lung compliance; i.e., the *lung* static pressure-volume curve is shifted to the left and has a steeper slope (Figure 1, lower panel).[5]

TABLE I Age-related changes in respiratory function and their relationships to perioperative pulmonary complications

Age-related change in respiratory function	*Clinical consequence*
↓ Chest wall compliance	↑ Work of breathing
↑ Lung compliance	↓ Ventilatory response to exercise
↑ Respiratory system resistance	
↑ Residual volume	Impaired gas exchange
↑ Small airways closure	
↑ Ventilation-perfusion mismatch	
↓ Respiratory muscle strength	↓ Secretion clearance
↓ Protective cough and swallowing reflexes	↑ Aspiration risk
Altered control of breathing	
↓ Responsiveness to imposed respiratory loads	Hypoventilation
↓ Responsiveness to hypoxemia and hypercarbia	Hypoxemia and hypercarbia
↑ Sensitivity to anesthetic agents and opioids	Respiratory failure in early postoperative period

Symbols: ↓ = decreased; ↑ = increased.

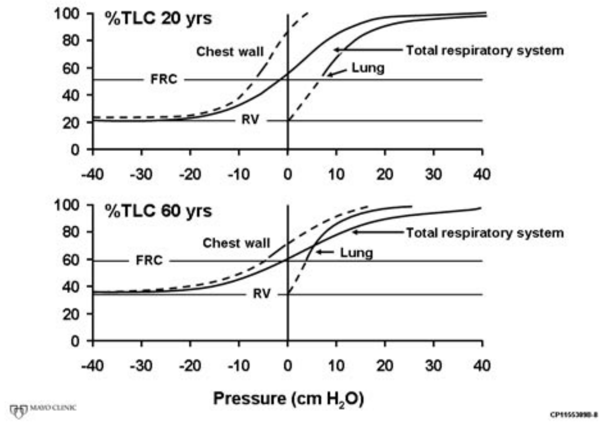

FIGURE 1 Pressure volume curves in a 20-yr-old (upper panel) and 60-yr-old (lower panel). Aging creates increases in lung compliance and decreases in chest wall compliance. The pressure-volume curve of the aged total respiratory system compliance (lung and thorax) is flatter and overall less compliant. TLC = total lung capacity; FRC = functional residual capacity; RV = residual volume. Reproduced with permission from J Appl Physiol 1968; 25: 664–71 (reference 5).

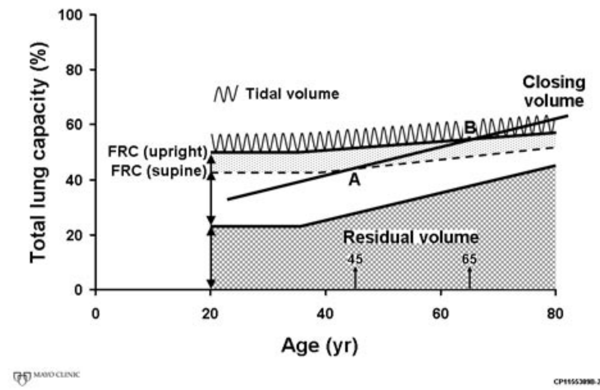

FIGURE 2 Lung volumes and aging. Residual volume and functional residual capacity (FRC) increase with aging while total lung capacity does not change. The closing volume increases with aging and exceeds FRC around age 65 in the upright position (B). However, because FRC is lower in supine body position, closing volume exceeds FRC at age 45 while supine (A). Modified with permission from Anesthesiol Clin North America 2000; 18: 47–58 (reference 4).

Chest wall

Chest wall compliance decreases with age due to structural changes of the intercostal muscles, intercostal joints and rib-vertebral articulations.[6,9] In addition, age-associated osteoporosis may increase in both dorsal kyphosis and anteroposterior chest diameter resulting in changes in the geometry of the thorax. This, together with increased chest wall stiffness, shifts the *chest wall* pressure-volume curve to the right (Figure 1, lower panel).[5]

The "remodelling" of the chest wall with aging flattens the curvature of the diaphragm, which leads to a reduction in maximal transdiaphragmatic pressure (P_{di}).[4] Reductions in respiratory muscle mass may also contribute to a decrease in the force produced by respiratory muscle activity. A reduction of skeletal muscle electromyographic activity by as much as 50% in the 70-yr-old individual is attributed to the loss of type II fast-twitch muscle fibres.[10] Indeed, in an electrophysiologic study, the electromyographic signal produced by twitch stimulation of the phenic nerve was modestly reduced in the elderly (mean age 73) compared to younger subjects (mean age of 29).[11] As a result, during voluntary maximal inspiratory effort P_{di} is lower in elderly than in younger patients and this may predispose to diaphragmatic fatigue;[12] in clinical settings this may translate into difficulties in weaning a patient from the ventilator.

Age-related changes in pulmonary mechanics, gas exchange and respiratory control

Static lung volumes

The overall effect of loss of inward elastic recoil of the lung with aging is somewhat balanced by the decline in chest wall outward force such that the total lung capacity (TLC) remains unchanged. However, at relaxed end-expiration, the rate of decrease in lung recoil with aging exceeds that of the chest wall, such that functional residual capacity (FRC) increases by 1 to 3% per decade (Figure 2). Because TLC remains unchanged, an increase in residual volume (5 to 10% per decade) results in a decrease in vital capacity (VC). After age 20, VC decreases 20 to 30 mL per year. The ratio of RV to TLC increases from 25% at 20 yr to 40% in a 70-yr-old subject.

Dynamic lung volumes

Longitudinal spirometric studies demonstrate progressive decreases in both forced vital capacity (FVC) (14–30 mL per year) and forced expiratory volume in

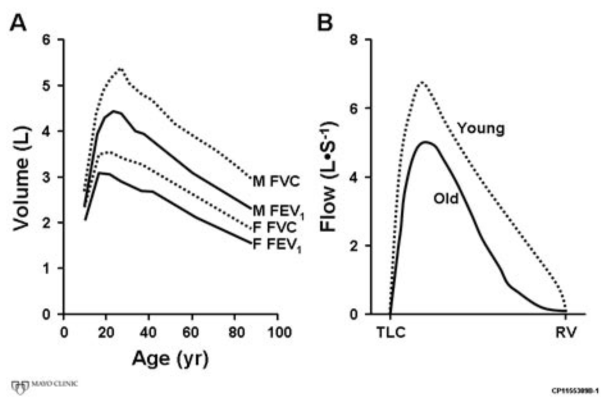

FIGURE 3 A) FEV_1 and FVC and age. (M, male, F, female). B) Expiratory flow-volume curve in younger (24 yr) and older (71 yr) subjects. TLC = total lung capacity; RV= residual volume. Reproduced with permission from Eur Respir J 1999; 13: 197–205 (reference 1).

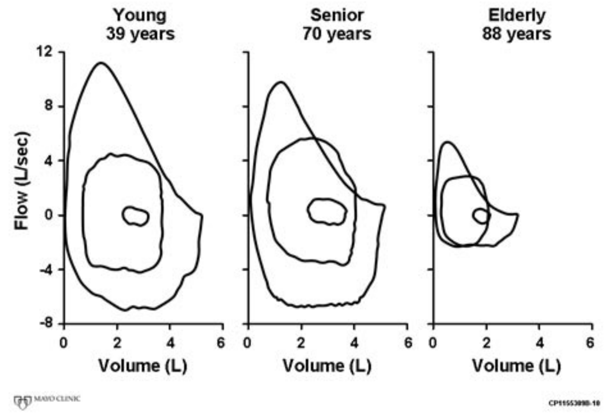

Figure 4 Maximal flow-volume loop (large loop) and two tidal flow-volume loops measured during rest (small size circles) and during maximal exercise (medium size circles) for subjects 39, 70, and 88 yr old. Elderly subjects have little ventilatory reserve to accommodate increased ventilatory demand. Reproduced with permission from Am J Respir Crit Care Med 1999; 160: 169–77 (reference 22).

one second (FEV_1) (23–32 mL per year) with aging in both men and women (Figure 3A).[13] After age 65, the decrease of FEV_1 is on average 38 mL per year.[14] Chronic smoking dramatically intensifies these age-related changes.[15] In healthy elderly subjects from 65 to 85 yr of age, the normal FEV_1/FVC ratio may be as low as 65% to 55%, and the rule of thumb that 70% represents the lower limit of the normal range for the FEV_1/FVC ratio is not applicable.[16] Lung function gradually deteriorates with aging even in individuals who attempt to maintain aerobic capacity over the sixth and seventh decades of life.[2,3] Surprisingly, in these individuals a greater decrease in FVC compared to FEV_1 results in a significant increase in the FEV_1/FVC ratio.[2]

Airway resistance

A decrease in small airway diameter with aging also contributes to a decrement in maximal expiratory flow.[17] Nonetheless, when adjusted for lung volume, age has no significant effect on measured airway resistance.[6] This is largely because the peripheral airways, which are most dependent on lung elastic recoil to maintain their calibre, make a relatively small contribution to the total resistance of the airways. However, changes to the small airways contribute to the obstructive flow pattern present even in lifetime non-smokers, implying that this pattern is characteristic of old age (Figure 3B).[18]

Maximal expiratory air-flow

Both peak expiratory flow and maximal inspiratory flow rates decrease with aging. The decrease in maximal expiratory flow is attributed to the loss of static lung elastic recoil pressure. These changes lead to an increase in the critical transmural pressure causing a dynamic compression of airways leading to increased upstream resistance, i.e., to expiratory airflow limitation.[19–21] This expiratory airflow limitation in elderly subjects causes significant alteration of the ventilatory response to exercise compared to younger adults.[22] Figure 4 shows a maximal flow-volume loop and two tidal flow-volume loops (the first measured during rest and the second during maximal exercise) for subjects aged 39, 70 and 88 yr. It is evident that older subjects have less ventilatory reserve to accommodate the increased ventilatory demand of heavy to maximal exercise due to marked airflow limitation.[22] The only strategy to increase minute ventilation in elderly subjects is by increasing the frequency of breathing. At the same time, the expiratory flow rates available to elderly subjects may increase the time required to exhale a given volume, which places further constraints on respiratory rate. Despite these limitations in the response to exercise in aged individuals, carbon dioxide and arterial oxygen homeostasis are generally well-maintained even during maximal exercise.[23]

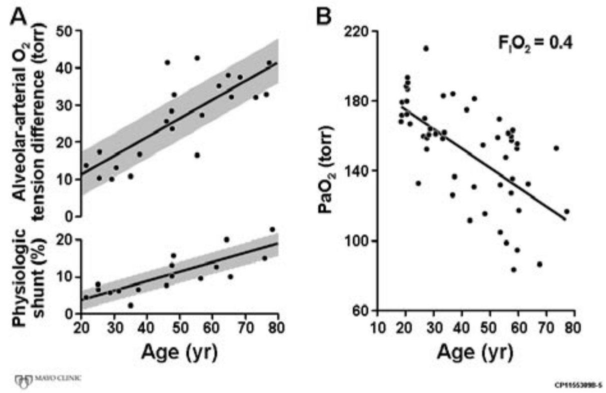

FIGURE 5A Age and gas exchange. A) The change in alveolar to arterial oxygen partial pressure difference and venous admixture (shunt) with age. B) Relationship between PaO_2 and age with spontaneous breathing during anesthesia using enflurane and 60% nitrous oxide. Reproduced with permission from Anesth Analg 1983; 62: 764–76 (reference 27).

Gas exchange

Arterial oxygenation gradually declines with aging,[24] whereas CO_2 elimination remains unaffected despite an increase in dead space ventilation.[25] The latter is due at least in part to a decline in CO_2 production associated with a decrease in basal metabolic rate. Several equations have been proposed to predict the PaO_2 as a function of age. Between the ages of 40 and 75, the following equation provides a reasonable estimate, and takes into account changes in both $PaCO_2$ and the body mass index (BMI): PaO_2 (mm Hg) = 143.6 - (0.39 × age) - (0.56 x BMI) - (0.57 × $PaCO_2$). After 75 yr of age, arterial oxygen tension did not correlate with BMI and $PaCO_2$, and remains relatively stable at around 83 mmHg.[26]

Several factors contribute to this age-related decline in PaO_2. In young seated subjects breathing air at rest the alveolar-arterial pressure difference for oxygen (A-aDO_2) is between 5 and 10 mmHg. An increase in the A-aDO_2 with age (Figure 5A) occurs because of an increase in ventilation/perfusion heterogeneity, thought to be caused by a decrease in alveolar surface area and the above mentioned premature closure of the small airways.[27] In addition, increased body mass index (i.e., obesity), which frequently accompanies aging, can contribute to widening of the A-aDO_2.

The diffusing capacity of the lungs for carbon monoxide decreases with aging.[28] The expected annual reduction in diffusing capacity approximates 0.3 and 0.2 $mL \cdot min^{-1} \cdot mmHg^{-1}$ in males and females, respectively,[9] and the changes are more pronounced after 40 yr of age. Women between the ages of 25 and 46 yr have the smallest annual decrease in diffusing capacity, suggesting a protective effect of estrogens, but after age 47 the yearly decline in diffusing capacity in women approaches that in men.[29] The decrease in diffusing capacity is attributed to ventilation/perfusion mismatching, decline in pulmonary capillary blood volume[28] and the loss of the alveolar surface area.[30]

Regulation of breathing

The breathing pattern changes with age, such that an elderly subject at rest has a lower tidal volume and a higher respiratory rate than a younger subject.[31] The mechanism responsible is not known, but it may represent an adaptation to decreases in chest wall compliance.[32] In addition, there may be changes in the function of both central chemoreceptors and peripheral mechanoreceptors in the chest wall and lung parenchyma. Compared to younger subjects, elderly individuals have an approximately 50% decrease in their ventilatory responses to hypoxia and hypercapnia.[33] Responses to isocapnic hypoxemia during sleep can be even more depressed, and elderly individuals may not arouse from the rapid eye movement phase of sleep until their oxyhemoglobin saturation decreases below 70%. Although in elderly subjects the ventilatory response to hypercapnia is less pronounced than in younger subjects, the ventilatory response to exercise is actually increased. This cannot be explained by either oxyhemoglobin desaturation or increased anaerobiosis.[34] Rather, it appears that increased ventilation compensates for increased efficiency of gas exchange, permitting the maintenance of isocapnia during exercise.[34]

Alterations in respiratory control mechanisms may also contribute to the finding that elderly patients may be less efficient at distinguishing different respiratory stimuli. Thus, a diminished perception of added resistive or elastic ventilatory loads with aging is attributed to altered integration of perception within the central nervous system.[35–37] Aging is also associated with a decline in the ability to perceive methacholine-induced bronchoconstriction when compared with younger subjects.[28] Blunting of the response to hypoxia and hypercapnia, as well as a lower ability to perceive respiratory sensations such as bronchoconstriction, represent a loss of important protective mechanisms which may result in lesser awareness of the disease and its delayed diagnosis in elderly patients.

Upper airway dysfunction

Loss of muscular pharyngeal support with aging predisposes elderly subjects to upper airway obstruction. In addition, respiratory effort in response to upper airway occlusion in obstructive sleep apnea (OSA) patients (as measured by swings in esophageal pressure) decreases with increasing age,[38] and this may impair the ability of the elderly OSA patients to open their airways. Repetitive episodes of upper airway obstruction during sleep occur in 24 to 75% of elderly individuals.[39] As measured by the apnea-hypopnea index, the prevalence of sleep-disordered breathing increases with age.[40] Chronic hypoxemia may lead to cognitive impairment, and OSA patients who experience frequent oxyhemoglobin desaturation may be more cognitively impaired than OSA patients who do not have similar episodes.[39]

A deterioration of protective mechanisms of cough and swallowing in the elderly may lead to ineffective clearance of secretions and increased susceptibility to aspiration. Loss of protective upper-airway reflexes is presumably due to an age-related peripheral deafferentation together with a decreased central nervous system reflex activity.[41] In addition, an increased prevalence of cerebrovascular and neurologic diseases in the elderly may be associated with dysphagia and an impaired cough reflex leading to the increased likelihood of pulmonary aspiration.[41] All the above factors may have significant perioperative implications and contribute to postoperative pneumonia in elderly individuals.[42]

AGING LUNGS AND PERIOPERATIVE PULMONARY COMPLICATIONS

Numerous factors related to the patient, surgery or anesthesia may contribute to the development of perioperative pulmonary complications. In this section, we briefly review the pathogenesis and epidemiology of perioperative pulmonary complications in general, and then discuss how the physiologic changes that accompany aging may affect these factors.

Mechanisms of postoperative pulmonary complications

Although the causes of postoperative pulmonary complications are multifactorial, current thought emphasizes the importance of changes in chest wall function, which is reflected by the fact that thoracic and upper abdominal surgeries are associated with the higher rates of postoperative pulmonary complications.[43] Changes in chest wall function lead to atelectasis, which forms within minutes after the induction of anesthesia, and is an important cause of intraoperative gas exchange abnormalities. Alterations in chest wall function that develop during anesthesia and surgery can persist into the postoperative period for several reasons. First, pain may limit the voluntary actions of the chest wall muscles. Second, surgery in the thoracic and abdominal cavities stimulates afferent nerves that innervate these structures and may result in a reflex inhibition of the respiratory muscles. Third, mechanical disruption of respiratory muscles may directly affect their ability to generate chest wall motion. Although laparoscopic surgical techniques may reduce these effects, they still cause stimulation of visceral afferents that significantly affect respiratory control. The net result of these changes is a decrease in the FRC, an impairment of VC, and a pattern of rapid and shallow breathing.

In addition to the above effects, which pertain to patients of all ages, other considerations apply to the elderly. Awake older non-anesthetized patients have less efficient gas exchange compared to younger subjects, as shown by the increase in both A-aDO_2 and physiologic pulmonary shunt (Figure 5A). Supine positioning for anesthesia induces a further decrease in FRC (Figure 2),[24] and the arterial oxygenation appears to be related to the relationship between preoperative closing capacity and intraoperative FRC.[44] Alveolar gas exchange during anesthesia is less efficient in the elderly (Figure 5B) and an inverse relationship exists between the increased age and arterial oxygenation in spontaneously breathing patients.[27,45] On the other hand, changes in chest wall and lung properties that accompany aging may actually help protect the elderly from anesthesia-induced changes in gas exchange. For example, atelectasis in dependent lung regions usually develops after induction of anesthesia. However, Gunnarsson *et al.*[46] found that atelectasis is not a prominent feature in elderly patients with healthy lungs during general anesthesia. Similarly, elderly patients with chronic obstructive pulmonary disease tend to show, at least initially following induction of anesthesia, less formation of atelectasis and less shunting compared with normal patients, due to their chronic lung hyperinflation.[47]

Risk factors for pulmonary complications

Several factors related to changes in aging respiratory system may contribute to pulmonary complications, as listed in Table I. Decreases in chest wall compliance may increase the work of breathing and increase risk for respiratory failure. Changes in lung mechanics, including an increased tendency for small airway closure, may impair gas exchange and promote atelectasis. Alterations in the control of breathing and increased sensitivity to anesthetic agents in the elderly may increase the incidence of postoperative sleep apnea episodes.

Age

Several studies find age to be a significant independent predictor of risk for perioperative pulmonary complications.[42,48,49] For example, in a recent study[48] significant multivariate predictors of pulmonary complications after non-thoracic surgery were age > 65 yr, and a smoking history of more than 40 yr. Pedersen *et al.*[50] found that risk factors for perioperative pulmonary complications included patient age older than 70 yr, chronic obstructive lung disease, major surgery, and the use of muscle relaxants during anesthesia. A recent literature review confirmed that advanced age is a risk factor for postoperative pulmonary complications, even after adjustment for other comorbid conditions.[51]

General health and cardiopulmonary status

General health status, as assessed by factors such as an American Society of Anesthesiologists physical status classification > 2, poor exercise capacity, and congestive heart failure may be associated with increased pulmonary risk in the elderly.[52–54] Gerson *et al.*[55] demonstrated that inability to perform two-minute supine bicycle exercise and increase the heart rate to values > 99 beats·min^{-1} was the best predictor of perioperative cardiopulmonary complications in patients older than 65 yr undergoing elective abdominal or noncardiac thoracic surgery. Among patients who were able to achieve these exercise criteria, complications occurred in 9.3%, with death in 0.9%. Among those unable to exercise satisfactorily, cardiac or pulmonary complications occurred in 42% with a mortality rate of 7.2%. Similarly, another study found that patients with better exercise tolerance by self-report, walking distance, or cardiovascular classification had lower rates of postoperative pulmonary complications.[56] A recent meta-analysis confirmed that congestive heart failure, more prevalent in elderly, represents a significant risk factor for postoperative pulmonary complications.[54]

Obesity

As in all other age groups, the prevalence of obesity is increasing in the elderly. Aging is associated with weight gain, and 75% of Americans who are clinically obese are between the ages of 51 and 69. Obesity itself does not appear to be a consistent independent risk factor for pulmonary complications after surgery.[54,57] However, respiratory system mechanics are abnormal in the obese (e.g., reduced chest wall compliance), which leads to a lower PaO_2 both while awake and while anesthetized.[26,58] (http://ihcrp.georgetown.edu/agingsociety/pubhtml/obesity2/obesity2.html, accessed May 20, 2006). The effects of obesity on arterial oxygenation may be compounded by advanced age, although this remains to be examined.

Swallowing and aspiration risk

Decreased respiratory muscle strength combined with diminished cough and swallowing reflexes may diminish secretion clearance and increase the risk of aspiration. The elderly frequently receive poor oral care, resulting in oropharyngeal colonization by potential respiratory tract pathogens.[59] Regarding aspiration risk, the loss of cough reflex or muscle strength secondary to neurologic disorders, combined with swallowing dysfunction, may predispose the patient to aspiration-induced lung infections.[59] For example, in patients with stroke, the prevalence of swallowing dysfunction ranges from 40 to 70% and many of these patients have silent aspiration.[59] The risk of aspiration is relatively high in the elderly because of the increased incidence of dysphagia and gastroesophageal reflux. Selective nasogastric tube decompression after abdominal surgery may reduce the risk of postoperative pulmonary complications.[60]

Anesthesia related factors

Inadequate reversal of muscle relaxation may be an important factor for postoperative complications in the elderly. Beard *et al.*[61] found a fourfold increase in postoperative pulmonary complications among patients who received intraoperative neuromuscular blockers. In general, pulmonary complications were three times higher among patients receiving a long-acting neuromuscular blocker than among those receiving shorter-acting relaxants.[62] The rate of postoperative pulmonary complications may be further increased in elderly patients who are overly narcotized, as hypoventilation leading to respiratory acidosis may potentiate the effects of residual neuromuscular blockade. To avoid these problems in the older patient, shorter acting neuromuscular blocking agents should be selected and the adequacy of reversal of neuromuscular block should be tested before tracheal extubation. A recent meta-analysis suggested that the use of short-acting neuromuscular blockers may be of "probable benefit" for reducing postoperative pulmonary complications.[60]

TABLE II Perioperative management of the elderly with increased respiratory risk

PREOPERATIVE	
Evaluation of pre-existing pulmonary risk	• Assess general physical status (pulmonary, cardiac, neurologic disease) and treat any reversible signs/symptoms Use spirometry only as guide for treatment Order chest radiogram only when necessary to evaluate symptoms Order arterial blood gases only to evaluate signs/symptoms Conduct careful assessment of severity of obstructive sleep apnea (plans for postoperative monitoring) • Preoperative "optimization" of pulmonary function Cessation of cigarette smoking Treat infection (antibiotics) Treat reversible bronchospasm (bronchodilators, corticosteroids) Consider postponing elective surgery to improve pulmonary function • Education regarding postoperative deep breathing/incentive spirometry • Enforce strategies for postoperative early ambulation (improved pain management, etc)
Anesthetic/Surgical Planning	• Consider regional analgesia for pain control, not necessarily to reduce the pulmonary risk • Limit duration of surgery (risk increased after > three hours) • If feasible use of laparoscopic surgical techniques
INTRAOPERATIVE	
	• Consider laryngeal mask, especially in those with bronchospasm (use inhalational agents, intraoperative use of bronchodilators, avoid histamine releasing drugs) • Careful and vigilant use of long acting muscle relaxant (to avoid postoperative muscle weakness) • Consider increased sensitivity to opioids in elderly-use multimodal analgesic therapy • Use of local anesthetics for operative field infiltration (hernia repair, minimally invasive surgery) • Use of adjuvant anesthetic drugs: consider dexmedetomidine (*iv* infusion), clonidine (with regional blocks) • Maintain adequate hydration to allow mobilization of airway secretions • Mechanical ventilation: conduct vital capacity maneuvers (lung expansion followed by PEEP, i.e., "alveolar recruitment") to achieve and maintain adequate oxyhemoglobin saturation • Limit high inspired oxygen concentrations to reduce development of resorption atelectasis • Maintain $PaCO_2$ at levels similar to those while awake-do not hyperventilate the lungs especially for "CO_2 retainers" • Use "permissive hypercapnia", and avoid high pressure/ large tidal volume ventilation which may cause volutrauma or barotrauma
POSTOPERATIVE	
	• Supplementation of inspired oxygen as needed • Maintain tracheal intubation until full reversal of neuromuscular blocking drugs is achieved • Continue effective pain management and minimize respiratory depression (opioids). Use multimodal therapy such as ketorolac, dexmedetomidine, clonidine, regional blocks, etc. • Early postoperative respiratory therapy (deep breathing, incentive spirometry) • Consider early postoperatively use of CPAP or BiPAP in selected patients; this may reduce the need for tracheal reintubation • Encourage early ambulation • Close monitoring of patient with known or suspected obstructive sleep apnea • Continue adequate hydration to allow mobilization of secretions

For more comprehensive reading regarding risk assessment and strategies to reduce perioperative pulmonary complications across general surgical population see recently published guidelines from the American College of Physicians.[51,54,60]

PEEP = positive end-expiratory pressure; CPAP = continuous positive airway pressure; BiPAP = bilevel positive airway pressure.

MINIMIZING PULMONARY COMPLICATIONS

Assessment of pulmonary risk factors and "optimization" for surgery

Although the results of pulmonary function testing, including measurement of arterial blood gases, have proven useful in predicting pulmonary function after lung resection, spirometry does not predict postoperative pulmonary complications after abdominal surgery.[56,63] For example, the degree of airway obstruction, as assessed by the FEV_1, is not a significant independent risk factor for the development of postoperative respiratory failure, even in smokers with severe lung disease.[64] Thus, pulmonary function tests should be viewed primarily as a management tool to optimize preoperative pulmonary function.[56] Preoperative spirometry may be useful to monitor the degree of bronchoconstriction in patients with asthma and the therapeutic response to bronchodilators. This may be especially valuable in elderly patients who occasionally have difficulty perceiving the status of their disease.

To minimize perioperative pulmonary complications in the elderly, it is of utmost importance to optimize preoperative respiratory function. This begins with a careful assessment of the patient's general physical status, with particular attention to the cardiovascular and respiratory system (Table II). Tests such as spirometry, chest radiograms, and arterial blood gases should be obtained as indicated from the history and physical examination as a part of this evaluation, but should not be routinely ordered.[51] Specific treatment of any disorder identified should be instituted preoperatively if such treatment is likely to result in improved functional status, so long as the benefit outweighs any risk from surgical delay. For example, any patient with a reversible component of airway obstruction must be treated with bronchodilators and/or corticosteroids while those with pulmonary infection must receive antibiotics. Patients who smoke should be given assistance to quit[65,66] and patients with OSA should have their status evaluated and properly treated with measures such as continuous positive airway pressure (CPAP). More intensive postoperative monitoring of oxygenation and ventilation may be required in such patients.

Patients should also be educated regarding the postoperative use of lung recruitment maneuvers, i.e., incentive spirometry, which is of demonstrated benefit in reducing postoperative pulmonary complications.[60] Preoperative education in these maneuvers reduces pulmonary complications more efficiently compared with instruction of patients after surgery.[67,68] The importance of early ambulation, and the means that will be employed to accomplish this goal, should also be reviewed.

Conduct of anesthesia/surgery

Surgical techniques

When surgically feasible, laparoscopic techniques should be considered in elderly patients with pulmonary compromise. However, significant changes in postoperative respiratory function can also occur following laparoscopic surgery so that their use does not guarantee a postoperative course free of complications.[60]

General vs regional anesthesia

In considering pulmonary complications, there are no convincing data to suggest that pulmonary outcomes differ between general and regional anesthetic techniques, therefore, this should not be the basis for anesthetic choice.[60] In particular, regional anesthesia may not necessarily be safer for the lungs of the elderly patient, as techniques such as subarachnoid block may be associated with alterations in chest wall muscle tone that may be poorly tolerated in the elderly, especially individuals with chronic obstructive pulmonary disease.

Intraoperative and postoperative analgesia

As in all patients, appropriate planning for postoperative pain control is necessary. There is a long-standing debate as to whether neuraxial techniques such as epidural analgesia reduce the frequency of postoperative pulmonary complications. Although there is no doubt that regional techniques provide excellent analgesia, their specific benefits with respect to pulmonary outcomes are much less clear.[43] A meta-analysis conducted by Rodgers *et al.*[69] concluded that regional techniques may confer a functional benefit, however many of the studies used in this and other meta-analyses have methodological limitations. More recent large clinical trials (not blinded) found few differences in outcomes between those receiving and not receiving epidural analgesia, with the exceptions that: 1) respiratory failure was less frequent for some types of operations, and 2) postoperative pain control was improved by epidural analgesia.[70] In a blinded trial, Jayr *et al.*[71] demonstrated that epidural techniques provide superior postoperative analgesia, but do not affect the frequency of postoperative pulmonary complications. In another blinded trial, Norris *et al.*[72] was unable to demonstrate a major outcome benefit of an epidural anesthetic technique, other than slightly shorter times to tracheal extubation. The above findings should not discourage the use of these valuable techniques in the elderly, but the evidence does not support their use to minimize pulmonary complications. The use of a full range of adjunctive analgesia techniques, such as infiltration with local anesthetics, peripheral nerve blocks, non-steroidal anti-inflammatory agents, and others as part of a "multi-modal" approach is appropriate.

Anesthetic drugs and adjuvants

The dosing of all anesthetic drugs should reflect differences in pharmacokinetics and pharmacodynamics that accompany aging. Opioids represent a class of drugs with particular significance to respiratory function in the elderly. As elderly patients may be particularly sensitive to opioid analgesics,[73,74] they should be titrated carefully in order to avoid postoperative respiratory depression.

Airway and ventilatory management

As discussed above, elderly patients may have altered upper oropharyngeal reflexes, and in such cases it may be desirable to conduct rapid sequence anesthetic induction in order to prevent pulmonary aspiration. Preoxygenation by performing only four deep breaths prior to induction of anesthesia may be insufficient in the elderly patients, who require a full three minutes of 100% oxygen breathing to avoid oxyhemoglobin desaturation during rapid sequence induction.[75] In patients with intact oropharyngeal reflexes but significant reactive airway disease, avoidance of endotracheal intubation by use of devices such as the laryngeal mask airway may be preferable.

As discussed above, atelectasis may be a less important cause of intraoperative hypoxemia during general anesthesia in elderly patients,[46] however, in elderly obese patients atelectasis may play a significant role in deterioration of postoperative oxygenation.[76] There has been considerable recent interest in maneuvers designed to recruit atelectatic lung regions. A variety of studies have shown that the isolated application of positive end-expiratory pressure (PEEP) does not predictably reverse atelectasis or increase arterial oxygenation.[77] To reexpand the atelectatic lung, it is necessary to employ a prolonged VC maneuver with high inflation pressures,[78] referred to as a "recruitment maneuver". This maneuver should be followed by sufficient PEEP to maintain the alveolar units open.[78,79] A peak opening inspiratory pressure of at least 40 cm H_2O is needed to fully reverse anesthesia-induced collapse of healthy lungs,[80] and even higher if the patient is grossly obese.[58] During a recruitment maneuver, as with application of PEEP, arterial blood pressure needs to be closely monitored, particularly in the dehydrated elderly patient because of its potential to reduce preload and induce hypotension.

Postoperative management

Reversal of drug effects

During the immediate postoperative period it is important to carefully manage all drugs that may weaken the respiratory muscles or affect the drive to breathe. Thus, treatment of pain with opioids, sedation with benzodiazepines, and incomplete elimination of residual inhalational anesthetics may reduce the respiratory response to chemical (hypoxemia, hypercapnia) and mechanical load (increased airway resistance), and may result in hypoventilation and hypoxemia. The same concerns apply to patients who have their muscle relaxation inadequately reversed. The elderly may be especially sensitive to these considerations, not only because of altered pharmacokinetics and pharmacodynamics,[74] but because of the diminished functional reserve of their respiratory system.

Lung expansion maneuvers (incentive spirometry, intermittent positive-pressure breathing)

These maneuvers are the mainstay for postoperative prevention of pulmonary complications in the elderly. Presumably, lung expansion maneuvers lower the risk of atelectasis by increasing the mean lung volume, although the exact mechanism of benefit remains unclear. When effectively performed, these techniques may reduce the risk of pulmonary complications by approximately half.[81] In addition to these maneuvers, postoperative care of elderly patients should always include early mobilization, as well as the liberal use of more upright positions that increase FRC and may significantly improve gas exchange.[24]

Non-invasive ventilation

Elderly patients with altered respiratory function may need support to maintain ventilation after extubation in the immediate postoperative period. To avoid tracheal reintubation in patients recovering from acute respiratory failure, some have tried to use non-invasive positive-pressure ventilation through a tightly fitting nasal mask with bilevel positive airway pressure (BiPAP). With BiPAP, inspiratory positive airway pressure (used to provide inspiratory assistance) and expiratory positive airway pressure (used to prevent alveolar closure) can be adjusted independently. Bilevel positive airway pressure delivers CPAP but also senses when an inspiratory effort is being made and delivers a higher pressure during inspiration, therefore it is more efficient in supporting breathing. There is considerable variation amongst studies reporting the outcome of BiPAP in the setting of acute respiratory failure.[82–84] In theory, BiPAP should minimize the decline in lung volume after surgery and may reduce pulmonary complications, but this possibility has not been studied. It has been shown that the use of CPAP may decrease the incidence of tracheal reintubation and other severe complications in patients who develop hypoxemia after elective major abdominal surgery.[85]

Prolonged postoperative mechanical ventilation in the elderly

An increasing number of elderly patients receive intensive care treatment after surgery. Because of underlying pulmonary disease, loss of muscle mass, and other comorbid conditions, older persons have increased risk of developing respiratory failure requiring mechanical ventilation[86] in response to a variety of physiologic insults, including surgery. In patients with adult respiratory distress syndrome older age is clearly associated with higher mortality rates.[87,88] Similar data specific to mechanical ventilation made necessary by postoperative pulmonary complications are not available. Ely *et al.*[89] prospectively studied whether age represents an independent effect on the outcomes of patients requiring mechanical ventilation after admission to an intensive care unit. After adjustment for severity of illness, elderly patients spent a similar amount of time on mechanical ventilation and in the intensive care unit. This suggests that chronologic age should not be a restriction for mechanical ventilation in elderly patients with respiratory failure.[89] Nonetheless, age-related alterations of the respiratory system may impact respiratory fitness and may, at least theoretically, contribute to failure to wean from the ventilator.[90] Factors known to affect weaning include a decrease in lung elasticity, reduction in FVC, decreased respiratory muscle strength, and decreased chest wall compliance. Long-term ventilator dependence (defined as need for mechanical ventilation for more than six hours per day for more than 21 days) complicates up to 20% of the episodes of mechanical ventilation treated in the intensive care units. Long-term ventilator dependence falls disproportionately to patients aged 70 yr or older.[91]

Conclusion

Progressive changes in lung and chest wall compliance and the changes in lung morphometry lead to ventilation perfusion mismatching and diminished efficiency of gas exchange in the elderly. Respiratory muscle strength consistently declines with age in a setting where reduced chest wall compliance may increase the work of breathing. Increased sensitivity to respiratory depressants, diminished protective airway reflexes and altered response to hypoxemia with increasing age may pose additional risks for the development of postoperative respiratory complications. Anesthesiologists must be aware of these factors and provide close monitoring and vigorous respiratory care to elderly patients undergoing surgery and anesthesia.

Acknowledgements

Dedicated to our teachers Joseph R. Rodarte and Robert E. Hyatt.

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