History of anesthesia

Manisha S. Desai and Sukumar P. Desai

Although anesthetic properties of nitrous oxide and ether were discovered in the 1800s, surgical operations were likely carried out under varied degrees of analgesia from times immemorial. Opiates, alcohol, cannabinoids, belladona derivatives, soporific sponges, and mesmerism were used to offer relief during surgery and are a testament to man’s ingenuity.

Joseph Priestley (1733–1804, UK) discovered oxygen in 1771, and nitrous oxide in 1772. Humphry Davy (1778–1829, UK) discovered the analgesic properties of nitrous oxide in 1800 and termed it "laughing gas"; however, he did not use it in any clinical setting. In the United States, recreational use of ether and nitrous oxide was common in the 1840s (ether frolics and laughing gas parties). William E. Clarke (1815–1898, USA) removed one of Wells’ teeth painlessly while Colton performed the first successful public demonstration of ether anesthesia while surgeon John Collins Warren (1778–1856, USA) removed a vascular tumor from the neck of Edward Gilbert Abbott. October 16 has thereafter been celebrated as Ether Day, and the amphitheater in which the procedure took place, Ether Dome, has been preserved as a museum at Massachusetts General Hospital, Boston.

However, Wells’ reputation never recovered from this apparent fiasco, and his life ended tragically in 1848. William Thomas Green Morton (1819–1868, USA), an associate of Wells, was present during the failed demonstration. He consulted with Harvard professor Charles T. Jackson (1805–1880, USA) and conducted experiments with ether. On October 16, 1846 Morton performed the first successful public demonstration of ether anesthesia while surgeon John Collins Warren (1778–1856, USA) removed a vascular tumor from the neck of Edward Gilbert Abbott. October 16 has thereafter been celebrated as Ether Day, and the amphitheater in which the procedure took place, Ether Dome, has been preserved as a museum at Massachusetts General Hospital, Boston.

News about the anesthetic properties of ether and nitrous oxide spread rapidly, and other agents were investigated for such properties. Obstetrician James Y. Simpson (1811–1870, UK) introduced chloroform for relief of labor pain in Edinburgh in 1847. John Snow (1813–1858, UK) is recognized as the first physician to work full time as an anesthetist. Relief of labor pain remained controversial until Snow administered chloroform to Queen Victoria (1819–1901) during the birth of Prince Leopold in 1853, and Princess Beatrice in 1857.

Equipment to administer anesthetics developed over the next several decades, and the risk of anesthesia became evident as reports of anesthesia-related deaths appeared in newspapers and medical journals.

Karl Koller (1857–1944, Austria) discovered the local anesthetic properties of cocaine, when applied to the conjunctiva, in 1884. William S. Halsted (1852–1929, USA) used it for a nerve block later that year, and August Bier (1861–1949, Germany) performed the first clinical spinal anesthetic in 1898, and introduced intravenous regional anesthesia in 1908. Harvey W. Cushing (1869–1939, USA) and Ernest A. Codman (1869–1940, USA), while medical students, introduced anesthetic records in 1894. Caudal epidural anesthesia was introduced independently by Jean A. Sicard (1872–1929, France) and Fernand Cathelin (1873–1945, France) in 1901. Henry Edmund Gaskin Boyle (1875–1941, UK) introduced a
portable apparatus to administer nitrous oxide and oxygen in 1917. Lumbar epidural anesthesia was introduced by Fidel Pagés (1886–1923, Spain) in 1921. Torsten Gordh (1907–2010, Sweden) introduced lidocaine into clinical use in 1944. The routine use of intravenous barbiturate anesthesia (with agent pernoston) was introduced by Rudolph Bumm (1899–1942, Germany) in 1927. Harold R. Griffith (1894–1985, Canada) and Enid Johnson (1909–2001, Canada) introduced curare in 1942. The use of neuromuscular blockers greatly facilitated surgery in major body cavities, and mechanical ventilation. Laryngoscopy and tracheal intubation became routine procedures, and new drugs (local anesthetics, intravenous agents, and inhalation anesthetics) were introduced in subsequent decades. Comprehensive anesthesia machines and routine monitoring equipment were introduced in the 1960s and 1970s. Automatic blood pressure measuring devices, capnography, and pulse oximetry were introduced in the 1980s. Standards for intraoperative monitoring were developed at Harvard Medical School, and adopted by the American Society of Anesthesiologists in 1986. Technological changes have introduced ultrasound and echocardiography to our specialty, and anesthesiologists have expanded their scope of practice to include perioperative care, critical care, and the treatment of chronic pain. Ambulatory surgery and delivery of anesthesia care outside the operating rooms are recent developments.

Credit for the discovery of general anesthesia ought to be divided as follows – Clarke for the first use of ether for dental extraction, Long for introducing ether for general surgery, Wells for the introduction of nitrous oxide, Morton for the first successful public demonstration of ether, and Jackson for the instruction he provided to Morton. Anesthesia is truly one of the most important discoveries in medicine, and it is unique in that the discovery occurred over a very brief period in the 1840s and events related to its discovery took place in America.

Question
Which one of the following statements is TRUE about individuals deserving credit for the discovery of anesthesia?

a. William Thomas Green Morton was the first to use nitrous oxide successfully during a surgical operation.

b. Horace Wells successfully demonstrated the use of ether for dental extraction.

c. Charles T. Jackson was the first to discover the anesthetic properties of nitrous oxide.

d. Crawford W. Long was the first to use ether successfully during a surgical operation.

Answer

d. Crawford W. Long was the first to use ether during a surgical operation in 1842. William E. Clarke used ether during a tooth extraction a few months earlier. Horace Wells’ administration of nitrous oxide anesthesia during dental surgery was only partially successful since the patient cried out during the procedure. Charles T. Jackson advised Morton about the use of ether, and did not play a role in the discovery of the anesthetic properties of nitrous oxide. Morton was the first to publicly demonstrate the efficacy of ether as an anesthetic, four years after Long.
Preoperative anesthetic assessment

Emily L. Wang and Jeffrey Lu

Keywords

- Preoperative assessment
- Cardiovascular system evaluation
- Functional capacity
- ACC/AHA Guidelines on Perioperative Cardiovascular Evaluation and Care for Noncardiac Surgery
- Active cardiac conditions
- Clinical risk factors
- Classification of cardiac risk for noncardiac surgery
- Perioperative β-blockade
- Percutaneous coronary intervention
- Hypertension: perioperative management
- Pulmonary system evaluation
- Airway and anesthetic history
- Gastrointestinal reflux
- Neurologic conditions
- Diabetes mellitus
- Renal conditions
- Hepatic conditions
- Pregnancy
- Allergies
- Social history
- Family history evaluation
- Medications
- Physical exam
- Preoperative laboratory testing
- ASA Physical Status Classification System
- ASA NPO Guidelines for Fasting

Preoperative assessment: provides an evaluation of the patient’s anesthetic risk for the proposed procedure, and allows recommendations to be made that help maximize patient safety. The anesthetic risk evaluation is based on the knowledge of the patient and the surgery. The goals of a preoperative assessment include a history and physical examination (including airway evaluation, medication usage, and past anesthetic and surgical experiences), control of comorbidities and perioperative diseases, laboratory and cardiac testing as indicated, anesthetic risk assessment, anesthetic plan formulation, and patient education and informed consent. Significant abnormalities detected by the patient’s history, physical exam, and associate risk factors may necessitate further testing and evaluation if it will affect the patient’s treatment, management, or outcomes.

Cardiovascular system evaluation: cardiovascular status should be evaluated for all routine preoperative evaluations. Cardiovascular disease has a high prevalence in most patient populations, and cardiovascular complications may result in significant morbidity and mortality. It is important to assess functional capacity, symptoms that may indicate significant cardiac disease, and obtain information regarding prior cardiac events and test results.

Functional capacity: a patient’s functional capacity is based on history, and is expressed in the form “metabolic equivalent of task” (MET). MET is defined as the ratio of metabolic rate during a specific physical activity to a reference metabolic rate at rest, set by convention to 3.5ml O₂/kg/min or equivalently, 1 kcal/kg/h. There is an increased perioperative cardiac risk for patients unable to achieve a 4 MET functional capacity, which is roughly equivalent to climbing two flights of stairs or walking two city blocks.

American College of Cardiology (ACC) and American Heart Association (AHA) Guidelines on Perioperative Cardiovascular Evaluation and Care for Noncardiac Surgery: offers a step-wise approach in the following algorithm: “Cardiac evaluation and care algorithm for noncardiac surgery based on active clinical conditions, known cardiovascular disease, or cardiac risk factors for patients 50 years of age or greater.”

“Active cardiac conditions” definition:
1. Unstable coronary syndromes: unstable or severe angina, may include stable angina in unusually sedentary patients, recent MI (within 30 days).
2. Decompensated heart failure, or worsening or new-onset heart failure.
3. Significant arrhythmias: Mobitz II or third-degree AV block, symptomatic ventricular arrhythmias, supraventricular arrhythmias with uncontrolled ventricular rate, symptomatic bradycardia.
4. Severe valvular disease: severe aortic stenosis (valve area <1cm², pressure gradient >40 mm Hg, or symptomatic), or symptomatic mitral stenosis.

**Clinical risk factors** definition:
1. diabetes mellitus
2. renal insufficiency
3. history of cerebrovascular disease
4. history of ischemic heart disease
5. history of compensated or prior heart failure

**Classification of cardiac risk for noncardiac surgery:**
1. High risk (>5%): emergent (especially in the elderly), aortic and other major vascular, peripheral vascular, and prolonged procedures with major blood loss or fluid shifts.
2. Intermediate risk (<5%): carotid endarterectomy, head and neck, intraperitoneal and intrathoracic, orthopedic, and prostate procedures.
3. Low risk (<1%): endoscopic, superficial, cataract, and breast procedures.

Based on ACC/AHA guidelines, further testing is directed by clinical assessment findings in relation to the complexity and invasiveness of the proposed procedure. However, emergency surgical procedures preclude preoperative evaluation, and risk factor management may require intensive care or postoperative invasive cardiac interventions.

**Perioperative β-blockade:** two groups mandated for β-blockade according to AHA/ACC guidelines are patients already taking β-blockers, and vascular patients with recent positive provocative cardiac testing. It is also likely...
recommended for intermediate risk or vascular surgical procedures with the presence of more than one clinical risk factor.

Patients with previous history of percutaneous coronary intervention (PCI), balloon angioplasty, bare metal stents (BMS), or drug-eluting stents (DES) require antiplatelet therapy to prevent thrombosis. Patients with BMS are required to have at least four weeks of antiplatelet therapy (clopidogrel), and patients with DES are required to have 12 months of dual antiplatelet therapy (aspirin and clopidogrel). It is recommended to delay elective, planned surgical procedures for at least 14 days after balloon angioplasty, 30 to 45 days after BMS placement, and one year after DES placement.

In patients with hypertension, the physician should evaluate for a history of end-organ disease such as myocardial ischemia or infarction, renal failure, and cerebrovascular disease. Although blood pressure should be optimally controlled preoperatively, there are no absolute contraindications based on blood pressure that necessitate cancellation of an elective procedure.

**Pulmonary system evaluation:** history taking in patients with asthma or COPD should include details about duration, therapy, baseline condition, history of intubations, hospitalizations, and recent changes in medications such as steroids or antibiotics. Notably, sleep apnea is associated with an increased incidence of postoperative apnea, respiratory failure, and poorer outcomes, especially with the administration of opioids.

**Airway and anesthetic history:** a key feature of the preoperative assessment, it should include details on previous intubations – especially if the patient has a history of difficult intubations – and the patient’s prior anesthetic experience. History taking of prolonged intubations or possible tracheostomies should include etiology, and potential residual damage such as symptomatic tracheal stenosis. Attempts to retrieve the medical records and communicate the details to the anesthetizing team may be lifesaving. A history of previous postoperative nausea or vomiting, poor venous access, and other anxiety surrounding anesthesia such as mask “phobia” may predict future difficulties.

**Allergies:** allergy documentation must include the drug and reaction exhibited when administered. Appropriate history taking can help distinguish between a true drug allergy (often manifested as dyspnea or skin rashes) or a drug intolerance or side effect (typically gastrointestinal upset).

**Medications:** a detailed list of the patient’s current medications and dosing schedule must be confirmed. It is important to document both prescribed and nonprescribed medications, as there is potential for drug interactions with anesthetic agents. In general, most medications should be continued until the night before the surgery. It is typically recommended to discontinue all alternative and complementary medications prior to the procedure. Anticoagulants should not be discontinued without a discussion with the cardiologist or physician prescribing them. Chronic pain medications often result in tolerance and create challenges with postoperative pain management.

**Gastrointestinal conditions:** as pulmonary aspiration may lead to severe complications during anesthesia, the preoperative assessment includes evaluation of gastroesophageal reflux disease, dysphagia symptoms, gastrointestinal motility disorders, and metabolic disorders (e.g. diabetes mellitus) that may increase the risk of regurgitation. Gastrointestinal reflux details should include severity, frequency, impact of treatment if prescribed, current symptoms, and onset of symptoms during the night when lying flat.

**Diabetes mellitus:** diabetes is the most common endocrinopathy encountered preoperatively. A patient’s history of the disease should include the type of diabetes, insulin status, possible end-organ damage, and previous diabetic comas. Oral hypoglycemic medications should be continued until the evening before surgery. Patients on insulin therapy will likely need to have their doses adjusted in preparation for the procedure and associated fasting. Generally, short-acting insulin is held on the morning of the surgery, and long-acting insulin is continued at the usual or reduced dose. Serum glucose levels can be checked during the fasting period, and regular insulin can be administered as needed. Insulin pumps are usually continued perioperatively at the basal rate.

**Neurologic conditions:** for patients with neurologic conditions, such as a history of cerebrovascular disease, multiple sclerosis, dementia, or epilepsy, it is important to document baseline functional and neurologic impairments, as well as a description of the symptoms.

**Renal conditions:** for renal disease patients, an assessment of their baseline renal condition should be determined. For dialysis patients, the frequency and mode of administration of the dialysis should be documented, and a plan for timing of dialysis perioperatively should be discussed.

**Hepatic conditions:** for hepatic disease patients, an assessment of their liver function and condition should be ascertained. Acute and chronic hepatic disease can lead to increased anesthetic and surgical risk, which can manifest as coagulopathies, ascites, encephalopathy, and alterations in drug distribution and metabolism.

**Pregnancy:** women of childbearing age should have their last menstrual period documented, and asked if there is any change of pregnancy. For patients who are reliable historians, routine pregnancy testing is not warranted.

**Social history:** this should include details about tobacco use, alcohol intake, and illegal drug use. Drug abuse and alcoholism may lead to significant changes in tolerance of anesthetic agents, and potential for withdrawal perioperatively.

**Family history evaluation:** all preoperative assessments should discuss the patient’s familial history disposition for the life-threatening disease malignant hyperthermia. Pseudo-cholinesterase deficiency is another familial disease that may be suggested by a history of unexplained prolonged weakness or postoperative intubation in an otherwise healthy patient.
Physical exam: involves a general assessment of the patient, and a targeted exam focusing on the airway and cardiopulmonary system. Height, weight, blood pressure, heart rate, respiratory rate, temperature, and oxygen saturation (and if on supplemental oxygen) should be recorded. Auscultation of the heart and lungs should be noted for presence of murmurs, and abnormalities in cardiac rhythms or lung sounds. It is also recommended to do a brief baseline neurologic exam, as well as physical exam of the patient’s anatomy when procedures such as a nerve block, regional anesthesia, or invasive monitoring are planned. The airway exam should include evaluation of the patient’s mouth opening, ability to visualize the posterior pharyngeal structures, degree of neck mobility, thyromental distance, and dentition. Signs that a challenging tracheal intubation may be encountered include a short neck, limited range of motion of the neck, large tongue, and small mouth opening.

Preoperative laboratory testing: specific preoperative testing should be decided on an individual basis, and is appropriate depending on the nature of the procedure and the patient’s medical comorbidities. Routine laboratory testing for healthy, asymptomatic patients is not recommended when the history and physical exam do not detect any abnormalities. In order for a preoperative test to be considered valuable, the results would need to alter perioperative management.

A hemoglobin or hematocrit test is indicated if the surgery is associated with significant blood loss potential, fluid shifts, or if the patient has a complex systemic disease resulting in anemia. Platelet counts are indicated if the patient has a history of low platelets, or has a disease associated with diminished platelets such as preeclampsia. Coagulation studies are indicated if the patient has significant liver disease or known coagulopathic conditions.

EKG should be obtained if the patient has cardiac risk factors and a history of cardiac disease. There is no definitive recommendation for screening EKGs to be done, but most institutions use 50 or 60 years old as the age requirement. In the absence of ongoing symptoms or changes in cardiac status, a prior EKG within three to six months is generally acceptable.

Patients with chronic renal failure should have electrolytes, blood urea nitrogen, and creatinine tested prior to any significant surgery. Renal dialysis patients should have their potassium level drawn immediately prior to the procedure.

ASA Physical Status Classification System: this classification system reflects the patient’s condition and underlying disease complexity, and a patient’s ASA status generally correlates with their perioperative morbidity and mortality rate. More significant comorbidities may increase perioperative morbidity. For example, a relative risk of serious perioperative complications is 2.2 and 4.4 for ASA patient status 3 and 4 respectively.

Class 1: A normal, healthy patient; no disease outside surgical process
Class 2: A patient with mild to moderate systemic disease, medically well controlled, with no functional limitation
Class 3: A patient with severe systemic disease that results in functional limitation

Table 1.1 Guidelines for fasting

<table>
<thead>
<tr>
<th>Minimum fasting period</th>
<th>Clear liquids (water, fruit juices without pulp, clear tea, carbonated beverages, black coffee – does not include alcohol)</th>
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<tbody>
<tr>
<td>Breast milk</td>
<td>4 hours</td>
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<tr>
<td>Infant formula</td>
<td>6 hours</td>
</tr>
<tr>
<td>Nonhuman milk</td>
<td>6 hours</td>
</tr>
<tr>
<td>Light meal (e.g., toast and a clear liquid)</td>
<td>6 hours</td>
</tr>
<tr>
<td>Fried or fatty foods, meat</td>
<td>8 hours</td>
</tr>
</tbody>
</table>

(Adapted from: Vacanti et al., 2011, p. 14.)

Class 4: A patient with severe, incapacitating systemic disease that is a constant threat to life (functionally incapacitated)
Class 5: A moribund patient who is not expected to survive without the operation
Class 6: A declared brain-dead patient whose organs are being removed for donor purposes

An “E” is added to the classification to designate a patient in whom surgery is emergent.

ASA NPO guidelines for fasting: patients are required to be nil per os (NPO) prior to undergoing anesthesia to minimize the risk of aspiration. These guidelines are for elective procedures requiring general anesthesia, regional anesthesia, or sedation/analgesia (i.e., monitored anesthesia care), but are not for women in labor. In considering NPO times, both the type and amount of food ingested should be taken into account (see Table 1.1). Also, the type of liquid ingested is typically more important than the volume of liquid ingested. If the following guidelines are not met, the patient is considered to be at an increased aspiration risk. NPO guidelines for fasting do not apply for emergency surgical procedures.

Questions

1. A 55-year-old gentleman is seen in the preoperative clinic in anticipation of an upcoming hip replacement surgery. His current medical conditions are well controlled, and his vital signs are stable in the clinic. It is appropriate to continue his outpatient medications as currently prescribed until his day of surgery, except for the following medication:
   a. baby aspirin
   b. regular insulin
   c. simvastatin
   d. metoprolol
   e. omeprazole

2. An anesthetic preoperative evaluation appropriately involves the following except:
a. baseline functional capacity assessment
b. an EKG for a patient with a history of hypertension and hypercholesteremia
c. coagulation studies for a laparoscopic cholecystectomy
d. platelet count for a preeclamptic patient
e. potassium level check for a renal dialysis patient

3. A 62-year-old woman with a past medical history of compensated CHF, atrial fibrillation, and angina with activity, and peripheral vascular disease has a recent diagnosis of breast adenocarcinoma. She presents for preoperative evaluation for a modified mastectomy. Her functional capacity at baseline is 2 METs. Her vital signs include a heart rate of 90, blood pressure 135/88, respiratory rate 16, with oxygen saturation of 98% on room air. Based on the current ACC/AHA guidelines and care algorithm, which of the following would be the most appropriate course of action?
   a. proceed with planned surgery
   b. obtain noninvasive cardiac testing for further evaluation
   c. after improvement in heart rate control, proceed with the planned surgery
   d. obtain a chest radiograph
   e. postpone the surgery until her cardiologist approves her for the procedure

Answers
1. b. Patients who are on insulin therapy will need to have their doses adjusted because of the fasting period that is associated with their procedure preparation. As they should be appropriately NPO the day of their surgery, short-acting insulin is generally held on the morning of the procedure. Long-acting insulin is typically continued at the usual or reduced dose. Serum glucose levels can be checked, and regular insulin can be given as needed. However, it is not appropriate to continue the currently prescribed regular insulin dose as currently when the patient will be fasting.

2. c. The need for preoperative laboratory testing is based on the patient’s comorbidities and the proposed surgical procedure. It is not recommended to undergo routine laboratory testing for asymptomatic patients who have no abnormalities suspected on history or physical exam. Coagulation studies are indicated for patients who have known hepatic disease or coagulopathies. Furthermore, laparoscopic cholecystectomy procedures are not typically procedures that are associated with inducing significant coagulation abnormalities.

3. a. Based on the ACC/AHA Guidelines on Perioperative Cardiovascular Evaluation and Care for Noncardiac Surgery, this patient would proceed with the planned procedure. Applying the step-wise algorithm to the scenario, this is not an emergency noncardiac surgery. Also, it is important to note that this patient does not have any “active cardiac conditions” as defined by the ACC/AHA guidelines – she does not have decompensated heart failure, nor unstable or severe angina, and her atrial fibrillation is not associated with an uncontrolled ventricular rate. Moreover, as her breast procedure is classified as having low cardiac risk, she may proceed with the planned elective surgery.

Further reading
Obstructive lung disease: the two primary obstructive lung diseases often encountered perioperatively are chronic obstructive pulmonary disease (COPD) and asthma.

COPD: the most common pulmonary disease in the perioperative setting. It is the fourth leading cause of death in the United States. Tobacco exposure causes 85% of cases.

Definition and classification of COPD: COPD is a chronic lung disease characterized by expiratory airflow limitation, which is progressive over time. The airflow limitation is not fully reversible (in contrast to asthma), and it is associated with abnormal inflammatory response in the lungs.

**Table 2.1** Global Initiative for Chronic Obstructive Lung Disease staging criteria

<table>
<thead>
<tr>
<th>Stage</th>
<th>Spirometry</th>
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| 0 (at risk) | FEV1/FVC ≥70%  
FEV₁ ≥80% |
| 1 (mild)  | FEV1/FVC <70%  
FEV₁ ≥80% |
| 2 (moderate) | FEV1/FVC <70%  
FEV₁ 50%–80% |
| 3 (severe) | FEV1/FVC <70%  
FEV₁ 30%–50% |
| 4 (very severe) | FEV1/FVC <70%  
FEV₁ <30% |


- Symptoms of COPD include chronic cough, sputum production, dyspnea, and progressive exercise intolerance with dyspnea on exertion.
- Physical examination findings may include decreased breath sounds, wheezes, rhonchi, rales, and prolonged expiratory phase. Oxygen saturation is also useful to help stratify the patient’s surgical risk.
- Spirometry is used to confirm the diagnosis and classify the severity. Accepted criterion for COPD is the ratio of forced expiratory volume in the first second of expiration to forced vital capacity (FEV₁/FVC) <70% of predicted, and postbronchodilator FEV₁ <80% of predicted. The staging system used to classify disease severity is based on the percent of FEV₁.

Historically, COPD is subdivided into emphysema and chronic bronchitis, although many patients exhibit features of both processes.

Emphysema: characterized by the destruction of lung parenchyma with normal airways. It includes destruction of collagen and elastin in the alveolar walls (so the elastic recoil
of the lungs is decreased), which leads to airspace enlargement distal to the terminal bronchioles. This results in increased lung compliance, and hyperinflation and distortion of the chest wall.

*Chronic bronchitis*: characterized by inflammation of the airways, which is associated with increased mucus secretions and airway mucosa thickening. Chronic bronchitis produces airway obstruction, which can cause V/Q mismatch, hypoxia, and CO₂ retention.

*Pathophysiology of COPD*: the pathogenesis of COPD derives from the combined effects of inflammation, increased oxidative stress, and imbalance in the activity of proteinases and antiproteinases. The pathologic changes are present throughout the lung, and progress over time. In the large central airways, there is enlargement of mucous glands, hyperplasia of goblet cells, loss of cilia, and decreased ciliary function, which results in such symptoms of increased mucus production and abnormal mucus clearance. In the airway walls, there is infiltration of inflammatory cells, increased smooth muscle, and deposition of connective tissue. In the small airways, there is also chronic inflammation, which causes collagen deposition and airway remodeling. The pulmonary vasculature can also be affected by vessel wall inflammation, smooth muscle deposition, and fibrosis.

Expiratory airflow limitation occurs as a result of airway inflammation, edema, mucus accumulation, airway hyperplasia and fibrosis, bronchospasm, and loss of radial traction as connective tissue is destroyed. Expiratory flow is significantly reduced throughout expiration, and expiratory time is increased. Changes in lung volumes and capacities of COPD patients include increased total lung capacity (TLC), functional residual capacity (FRC), and residual volume (RV).

Hyperinflation occurs with COPD, which can be manifested by diaphragm flattening, rib elevation, and increase in the cross-sectional thoracic area. Ventilation–perfusion (V/Q) mismatching also occurs, and gas exchange is impaired. There is an increase in both physiologic dead space and shunt. Varying degrees of hypercarbia and hypoxemia occur in different patients.

*Figure 2.1* Flow–volume curve in normal and COPD patients. (From Vacanti et al. 2011. *Essential Clinical Anesthesia*, Cambridge University Press, p. 17)

*Figure 2.2* Changes in lung volumes and capacities with COPD. (From Vacanti et al. 2011. *Essential Clinical Anesthesia*, Cambridge University Press, p. 17)
Section 1: Preoperative care and evaluation

Pulmonary hypertension may result from the combined effects of chronic hypoxia and the direct pathologic changes of the pulmonary vasculature. Progressive pulmonary hypertension can cause right ventricular dysfunction and cor pulmonale.

Treatment of COPD:
- Treatment of stable COPD: smoking cessation is the only intervention that slows the progression of COPD. Yearly influenza vaccinations significantly decrease morbidity and mortality. Pharmacologic management is aimed at providing symptom relief, but does not change the disease progression. It is approached in a step-wise fashion. For early-stage COPD, short-acting inhaled bronchodilators are used for symptomatic relief. For more severe COPD, long-acting inhaled bronchodilators are used to help relieve dyspnea, and improve lung function and exercise tolerance. In severe COPD, inhaled corticosteroids help reduce the frequency of acute exacerbations. In patients with moderate to severe disease, combination therapy with long-acting $\beta_2$-agonists and inhaled corticosteroids may have additive benefits. Comprehensive, multidisciplinary pulmonary rehabilitation programs may provide improvement in exercise capacity and quality of life during all stages of COPD.
- Treatment of acute exacerbations of COPD: symptoms of acute exacerbations include worsened dyspnea, wheezing, cough, increased sputum, a change in the sputum characteristics, chest tightness, fever, and malaise. Acute exacerbations are often triggered by respiratory tract infections. Initial treatment includes escalation of bronchodilator therapy, oxygen therapy for hypoxia, antibiotics if there is evidence of bacterial infection, and possible systemic corticosteroids. The patient should be admitted to the hospital if they have progressive hypoxemia, hypercarbia, respiratory distress, or evidence of new heart failure. The highest risk of mortality is with progressive hypercarbia and respiratory acidosis. Noninvasive mechanical ventilation may be effective to decrease the need for intubation as well as the mortality. However, patients with refractory hypoxemia, severe acidosis, or respiratory arrest require intubation and mechanical ventilation.
- Treatment of end-stage COPD disease: limited treatment options for advanced COPD include domiciliary oxygen therapy, lung volume reduction surgery (LVRS), and lung transplantation. Oxygen therapy increases exercise capacity and improves survival, and is recommended for patients with $\text{PaO}_2 <55 \text{ mm Hg}$ or an arterial oxygen saturation ($\text{SaO}_2$) $<89\%$; or a $\text{PaCO}_2 <60 \text{ mm Hg}$ if the patient has pulmonary hypertension. Contrary to common belief, oxygen will not increase $\text{PaCO}_2$; any increases are most likely caused by changes in ventilation–perfusion distribution rather than decreased hypoxic ventilatory drive. LVRS is thought to improve chest wall mechanics in patients with severe hyperinflation. It is a high-risk palliative treatment, and few patients qualify.

Perioperative risk assessment of COPD: patients with COPD have a 2.7 to 4.7-fold increased risk of perioperative pulmonary complications. The degree of risk correlates with the severity of COPD. Common pulmonary complications are atelectasis, pneumonia, respiratory failure, and acute exacerbation of underlying chronic pulmonary disease. Other risk factors for perioperative pulmonary complications include patient’s age $>60$ years, ASA status II or higher, history of congestive heart failure, current smoking, and type of surgery. Highest risk surgeries are associated with aortic, thoracic, and upper abdominal procedures. Other increased risk surgeries include neurosurgery, head and neck surgery, emergency surgery, and prolonged surgery ($>3$ hours).

Current recommendations include pulmonary function tests (PFTs) for all lung resection candidates, and obtaining a chest radiograph for patients with known cardiopulmonary disease or those older than 50 years who are undergoing high-risk operations. Spirometry may be used to predict long-term functional status after a major lung resection. However, preoperative spirometry does not predict the risk of postoperative pulmonary complications. For other procedures, lab testing is an adjunct to clinical assessment and should be obtained in selected patients. Potential lab tests include chest radiographs, exercise testing, arterial blood gas analysis, and PFTs.

The potential benefit of a surgery should be weighed against the risk, especially if patients have an increased risk

<table>
<thead>
<tr>
<th>Table 2.2 Commonly used bronchodilator drugs</th>
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<tbody>
<tr>
<td><strong>Drug</strong></td>
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<tr>
<td>$\beta_2$-agonists:</td>
</tr>
<tr>
<td>Fenoterol</td>
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<tr>
<td>Albuterol</td>
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<tr>
<td>Levalbuterol</td>
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<tr>
<td>Terbutaline</td>
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<tr>
<td>Formoterol</td>
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<tr>
<td>Salmeterol</td>
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<tr>
<td>Anticholinergics:</td>
</tr>
<tr>
<td>Ipratropium bromide</td>
</tr>
<tr>
<td>Tiotropium</td>
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<tr>
<td>Methylxanthines:</td>
</tr>
<tr>
<td>Aminophylline</td>
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<tr>
<td>Theophylline</td>
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IV, intravenous; MDI, metered-dose inhaler; Neb, nebulizer.