



Veterinary Anesthesia and Analgesia

The Fifth Edition of Lumb and Jones



Edited by

Kurt A. Grimm • Leigh A. Lamont • William J. Tranquilli
Stephen A. Greene • Sheilah A. Robertson

WILEY Blackwell

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Dedication

The fifth edition of this text is dedicated to the many people who support and make up the specialty of veterinary anesthesia and analgesia including all animal care providers, veterinarians, and scientists striving to advance humane veterinary care.

The editors wish to dedicate our efforts in bringing the fifth edition of *Veterinary Anesthesia and Analgesia* to publication to our parents for imparting the values of hard work, loyalty, and patience; to our teachers and colleagues for the belief that scientific knowledge gives us the best chance to know what is real; to the animals in our care who have taught us so much; to our significant others for their support; and to those who learn from this text for making everything joyful and worthwhile.

Foreword

The extensively referenced content, important additions, and timely revisions of the fifth edition of *Veterinary Anesthesia and Analgesia* provide an impressive documentation of the basic and applied clinical science essential to the safe delivery of animal anesthesia and pain management. As such, this text continues to be the most complete source of information on this subject matter for students, practitioners, and specialists alike. The fifth edition once again sets a high standard as the most comprehensive textbook on veterinary anesthesia and analgesia within veterinary literature.

As previous editors of *Lumb and Jones' Veterinary Anesthesia*, we wish to acknowledge the efforts of the contributors, 85 in all, with special thanks to Drs. Grimm, Lamont, Tranquilli, Greene, and

Robertson for assuming the editorship of such a large endeavor. As we enter the 21st century, the publication of *Veterinary Anesthesia and Analgesia: The Fifth Edition of Lumb and Jones* in 2015 serves to highlight the importance, significance, and necessity of continually improving animal anesthesia and analgesia. With their combined efforts, the contributing authors and editors have admirably upheld this text's long-standing reputation as an indispensable resource in advancing and improving animal welfare.

William Lumb
Wynn Jones
John Thurmon

Preface

The first edition of *Veterinary Anesthesia* was published in 1973; the second edition followed in 1984. The third edition, entitled *Lumb and Jones' Veterinary Anesthesia*, was published in 1996. The fourth edition was renamed *Lumb and Jones' Veterinary Anesthesia and Analgesia* and was published in 2007. Now in its 42nd year, a fifth edition of this text is available to the veterinary profession and scientific community.

Many improvements have occurred in veterinary anesthesia and analgesia in parallel with the evolution of veterinary medicine, as each succeeding edition of this text updates and documents these advances. This effort has continued within the chapters and pages of the fifth edition. As the specialty of veterinary anesthesia and analgesia has become recognized and established throughout the world, the knowledge and clinical practice of sophisticated anesthesia and analgesia is no longer defined by its initial academic beginnings. This revision, entitled *Veterinary Anesthesia and Analgesia: The Fifth Edition of Lumb and Jones*, reflects the current editors' collective view that the specialty of veterinary anesthesia and analgesia has secured a well-deserved and respected place among recognized specialties within the greater global veterinary community. This accomplishment is evidenced by the international makeup of the contributing authorship of the fifth edition and is supported by the worldwide practice of more advanced anesthesia and pain management care.

As editors, we have endeavored to provide information on multiple species and the important physiology and pharmacology for safe delivery of anesthetics and analgesics in a variety of patients and clinical conditions. The volume of space required in presenting newer knowledge and evolving issues pertinent to veterinary anesthesia and analgesia in 2015 makes the retention of much of the previous editions' text impossible. Fortunately, this information, much of which is of historical interest, remains available to interested individuals within earlier editions. As such, we wish to acknowledge the valuable contributions made by all previous authors and editors of this landmark text.

This edition has over 80 contributing authors, offering a wide range of scientific training and clinical experience. Many contributors are anesthesiologists, but a number of authors are specialists in other areas, including clinical pharmacology, surgery, medicine, critical care, cardiology, urology, and laboratory animal medicine. It is hoped that this diversity in author expertise will help provide a more comprehensive perspective when managing patients suffering from a variety of clinical conditions and diseases.

The editors of the fifth edition are indebted to the contributing authors for the many hours each devoted to the preparation of their

chapters. Many of these authors have dedicated their careers to the advancement of veterinary anesthesiology, pain management, and the humane treatment of animals. In so doing, they have made numerous contributions to the advancement of veterinary medicine during their lives. Among these is Dr. Steve C. Haskins, whose unexpected passing saddened the veterinary community worldwide. His chapter contributions on anesthetic monitoring in the third, fourth, and fifth editions may be regarded as one of the most comprehensive discussions of the fundamental principles of anesthetic monitoring. Dr. Haskin's dedication to the discovery of new knowledge and his love of teaching were driven by his joy of seeing students learn. Our loss, with his passing, as with all great teachers, is immeasurable.

As the current editors, it is our hope that this revision will be viewed both as a textbook and as a comprehensive source of scientific knowledge relevant to the clinical management of anesthesia and provision of analgesic therapy. Information on the immobilization and anesthesia of wild, zoo, and laboratory animals will be found in chapters devoted to the comparative aspects of anesthesia in these species. In addition to chapters on cardiovascular, respiratory, nervous system, and acid-base physiology, the pharmacology of various classes of drugs employed in the delivery of anesthesia and analgesia has been updated. Chapters on anesthetic equipment, monitoring, and regional analgesic techniques are provided. Chapters covering anesthetic and analgesic considerations for patients undergoing renal replacement therapy, cardiac pacemaker implantation, and cardiopulmonary bypass have been added. Chapters continue to be devoted to the anesthesia of specific species and classes of animals including dogs, cats, horses, swine, ruminants, laboratory animals, zoo animals, free ranging terrestrial and aquatic mammals, birds, reptiles, amphibians, and fish. Anesthetic considerations for patients with conditions affecting specific body systems have been consolidated into single-system chapters.

We would like to personally thank the many contributing authors for their generous sharing of knowledge and our families and co-workers for allowing us the time necessary to complete this work. Finally, we thank the staff at Wiley Blackwell for their support and encouragement.

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SECTION 1

General Topics

1

Introduction: Use, Definitions, History, Concepts, Classification, and Considerations for Anesthesia and Analgesia

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Introduction

Veterinary anesthesia continues to evolve as a science and specialty within the veterinary profession. The major drivers of change are advances in medical technology and pharmaceutical development for domesticated animals or those adapted from human anesthesiology; research in physiology, pharmacology, and clinical trials for human and veterinary patients that provide better evidence-based guidance for patient care; and socioeconomic and demographic changes in countries where animals serve evolving roles. Veterinary anesthesiologists will continue to be advocates for patient safety, humane care through education about pain management and quality of life, and educators of the profession and society at large about the current best practices in anesthesia, analgesia, and pain management.

Use of anesthesia, sedation, and analgesia

Proper use of anesthetics, sedatives, and analgesics can alleviate pain, create amnesia, and produce muscle relaxation essential for safe and humane patient care [1]. Important uses include facilitation of immobilization for various diagnostic, surgical, and therapeutic procedures; safe transportation of wild and exotic animals; and euthanasia and the humane slaughter of food animals. Anesthesia, sedation, and analgesic drug administration are not without significant patient risk and are not recommended for trivial reasons. The continued development of better techniques and drugs along with the concerted and continuing effort to educate veterinary care providers has minimized the overall risk of anesthesia and pain alleviation in an ever-increasing and more sophisticated patient care environment. Any discussion with the animal-owning public, such as that occurring with owners when obtaining

informed consent, requires use of proper terminology to convey the issues central to the safe delivery of veterinary anesthesia and pain therapy.

Definitions

The term *anesthesia*, derived from the Greek term *anaesthesia*, meaning ‘insensibility’, is used to describe the loss of sensation to the entire or any part of the body. Anesthesia is induced by drugs that depress the activity of nervous tissue locally, regionally, or within the central nervous system (CNS). From a pharmacological viewpoint, there has been a significant redefining of the term general anesthesia [2]. Both central nervous stimulants and depressants can be useful general anesthetics [3].

Management of pain in patients involves the use of drugs which are often called *analgesics*. The term is derived from *an*, which is the negative or without, and *alges(is)*, meaning pain [4]. Clinical management of pain often results in varying degrees of effectiveness that represent states of *hypoalgesia*, or decreased sensation of pain. It is important to understand that the administration of an analgesic drug does not necessarily create the state of analgesia.

Several terms are commonly used in describing the effects of anesthetic and pain-inhibiting drugs:

- 1 *Analgesia* is the absence of pain in response to stimulation which would normally be painful. The term is generally reserved for describing a state in a conscious patient [5].
- 2 *Nociception* is the neural process of encoding noxious stimuli [5]. Nociception is the physiologic process that underlies the conscious perception of pain. Nociception does not require consciousness and can continue unabated during

- general anesthesia if techniques that interrupt or inhibit the transduction, transmission, and modulation of nociceptive stimuli are not included.
- 3 *Pain* is an unpleasant sensory and emotional experience associated with actual or potential tissue damage, or described in terms of such damage [5].
 - 4 *Tranquilization* results in behavioral change wherein anxiety is relieved and the patient becomes relaxed but remains aware of its surroundings. Tranquilizers are drugs that result in tranquilization when administered; however, many prefer to use the term anxiolytic or anti-anxiety drug when describing drugs that result in both reduced anxiety and relaxation.
 - 5 *Sedation* is a state characterized by central depression accompanied by drowsiness and some degree of centrally induced relaxation. The patient is generally unaware of its surroundings but can become aroused and is responsive to noxious stimulation. Sedatives are not recommended by themselves to immobilize a patient during times which painful stimuli are likely to occur.
 - 6 *Narcosis* is a drug-induced state of deep sleep from which the patient cannot be easily aroused. Narcosis may or may not be accompanied by antinociception, depending on the techniques and drugs used.
 - 7 *Hypnosis* is a condition of artificially induced sleep, or a trance resembling sleep, resulting from moderate depression of the CNS from which the patient is readily aroused.
 - 8 *Local analgesia (anesthesia)* is a loss of pain sensation in a circumscribed body area.
 - 9 *Regional analgesia (anesthesia)* is insensibility to pain in a larger, though limited, body area usually defined by the pattern of innervation of the effected nerve(s) (e.g., paralumbar nerve blockade and anesthesia).
 - 10 *General anesthesia* is drug-induced unconsciousness that is characterized by controlled but reversible depression of the CNS and perception. In this state, the patient is not arousable by noxious stimulation. Sensory, motor, and autonomic reflex functions are attenuated to varying degrees, depending upon the specific drug(s) and technique(s) used.
 - 11 *Surgical general anesthesia* is the state/plane of anesthesia that provides unconsciousness, amnesia, muscular relaxation, and hypoaesthesia sufficient for painless surgery.
 - 12 *Balanced anesthesia* is achieved by the simultaneous use of multiple drugs and techniques. Drugs are targeted to attenuate specifically individual components of the anesthetic state, that is, amnesia, antinociception, muscle relaxation, and alteration of autonomic reflexes.
 - 13 *Dissociative anesthesia* is induced by drugs (e.g., ketamine) that dissociate the thalamocortical and limbic systems. This form of anesthesia is characterized by a cataleptoid state in which eyes remain open and swallowing reflexes remain intact. Skeletal muscle hypertonus persists unless a strong sedative or peripheral or central muscle relaxant is co-administered.

Brief history of animal anesthesia

In 1800, Sir Humphrey Davy suggested that nitrous oxide might have anesthetic properties. Twenty four years later, H. H. Hickman demonstrated that pain associated with surgery in dogs could be alleviated by inhalation of a mixture of nitrous

oxide and carbon dioxide. He reasoned that the latter increased the rate and depth of breathing, thus enhancing the effects of nitrous oxide. More recent studies have shown that unconsciousness can be induced in 30–40 s in piglets breathing carbon dioxide (50%) in oxygen (50%) [6].

It was not until 1842 that diethyl ether was used for human anesthesia. Two years later, a dentist, Horace Wells, rediscovered the anesthetic properties of nitrous oxide. Although this finding was neglected for several years, nitrous oxide was introduced to human anesthesia in 1862. C. T. Jackson, a Boston physician, was the first to employ diethyl ether extensively in animals [7].

Chloroform was discovered by Liebig in 1831, but it was not until 1847 that it was first used to induce anesthesia in animals by Flourens and in people by J. Y. Simpson of Edinburgh, Scotland. With the introduction of chloroform, reports began to appear in the veterinary literature of its use in animals. Dadd routinely used general anesthesia in animals and was one of the first in the United States to advocate humane treatment of animals and the application of scientific principles (i.e., anesthesia) in veterinary surgery [8].

In 1875, Ore published the first monograph on intravenous anesthesia using chloral hydrate; 3 years later, Humbert described its use in horses. Pirogoff was the first to attempt rectal anesthesia with chloral hydrate in 1847. Intraperitoneal injection was first used in 1892 in France. Thus, various routes of administration of general anesthetics to animals had been identified and minimally investigated by the end of the 19th century.

After the initial isolation of cocaine by Albert Niemann of Germany in 1860, Anrep, in 1878, suggested the possibility of using cocaine as a local anesthetic. In 1884, Kohler used cocaine for local anesthesia of the eye, and Halsted described cocaine regional anesthesia a year later. Its use was popularized by Sir Frederick Hobday, an English veterinarian. Thereafter, G. L. Corning was credited for using cocaine for spinal anesthesia in dogs in 1885. From his description, however, it would appear that he induced epidural anesthesia. In 1898, August Bier of Germany induced true spinal anesthesia in animals and then in himself and an assistant [9].

While local infiltration was popularized by Reclus (1890) and Schleich (1892), conduction regional anesthesia had been earlier introduced by Halsted and Hall in New York in 1884. These techniques increased in popularity with the discovery of local anesthetics less toxic than cocaine. These developments enabled Cuille and Sendrail (1901) in France to induce subarachnoid anesthesia in horses, cattle, and dogs. Cathelin (1901) reported epidural anesthesia in dogs, but it remained for Retzgen, Benesch, and Brook to utilize this technique in larger species during the 1920s. Although paralumbar anesthesia was employed in humans by Sellheim in 1909, it was not until the 1940s that Farquharson and Formston applied this technique in cattle. Despite these promising advancements in local analgesic techniques in the latter half of the 19th century, likely owing to the many unfavorable results, general anesthesia and humane surgery were not readily adopted by the veterinary profession until well into the 20th century. It is sad to say, but a 'heavy hand,' without analgesia/anesthesia or even sedation, was the stock in trade of many 'large animal' practicing veterinarians well into the latter half of the 20th century.

In smaller domestic animals, diethyl ether and chloroform were commonly administered in the early part of the 20th century. However, general anesthesia became more widely accepted after

the discovery of barbiturates in the late 1920s and, in particular, with the development of pentobarbital in 1930. Barbiturate anesthesia received an additional boost with the introduction of the thiobarbiturates and particularly thiopental in 1934. Because of rough, prolonged recovery, the acceptance of barbiturate general anesthesia in larger species of animals was delayed until phenothiazine derivatives were also introduced by Charpentier in France in 1950.

General anesthesia of large farm animals was further advanced by the discovery of fluorinated hydrocarbons and the development of 'large animal' inhalant anesthetic equipment for safe administration. The discovery of newer classes of drugs together with their safe co-administration (e.g., tranquilizers, opioids, α_2 -adrenergic receptor agonists, dissociatives, muscle relaxants, and inhalant anesthetics) has further advanced the safety and utility of veterinary anesthesia for both large and small animal species [10].

The modern era of veterinary anesthesia was initiated during the last three decades of the 20th century facilitated by the establishment of anesthesia specialty colleges within North America and Europe. Stated organizational missions were the improvement of patient safety and the development of new techniques and knowledge paralleling the advances made in human anesthesia. New drugs and techniques are continually being evaluated for clinical usefulness in a variety of species and individual patient pathologies. In addition, an appreciation of patient monitoring for improved safety has led to the adaptation of technologies such as pulse oximetry, capnography, and blood pressure measurement. The veterinary anesthesiologist's value as a member of the patient care team has led to an ever-increasing presence in private veterinary practice. A more sophisticated approach to anesthesia care has become evident with an increasing patient age demographic. This demand will continue to expand the anesthesiologist's importance to our profession beyond the traditional roles of university instructors and pharmaceutical researchers. Demand has also been bolstered by the veterinary profession's quest to improve patient quality of life through better pain management. Many anesthesiologists have been leaders in this area through continued research and the creation of evidence-based species-specific pain-assessment scales and therapeutic guidelines.

History of North American organizations

During the late 1960s and early 1970s, a small group of physician anesthesiologists made it possible for a number of future diplomates of the American College of Veterinary Anesthesiologists (ACVA), now the American College of Veterinary Anesthesia and Analgesia (ACVAA), to participate in their training programs and to learn about the development of new anesthetic drugs and techniques. Among these physicians were Robert Dripps, University of Pennsylvania; Arthur Keats, Baylor University; Mort Shulman and Max Sadoly, University of Illinois; and Edmond I. Eger, University of California Medical College. During this same period, E. W. Jones (Oklahoma State University) and William Lumb (Colorado State University) were making significant contributions to the field of veterinary anesthesiology. Jerry Gillespie had made significant contributions through his work on the respiratory function of anesthetized horses and William Muir was reporting on the cardiopulmonary effects of various anesthetic drugs in various species.

Even though there were many dedicated faculty within North American veterinary colleges and research laboratories, it was not until 1970 that a major effort was made at organizing veterinarians interested in anesthesiology as a stand-alone specialty. Initially, the American Society of Veterinary Anesthesia (ASVA) was established. Membership of the ASVA was open to all individuals working in the veterinary profession who had an interest in veterinary anesthesiology. In 1970, the first organizational meeting was held in conjunction with the American Veterinary Medical Association (AVMA) to coordinate the efforts/interest of all those wishing to develop the specialty of veterinary anesthesiology. Their primary goal was to improve anesthetic techniques and to disseminate knowledge whenever and wherever possible. Charles Short was elected the first President of the new society. The ASVA was designed expressly to promote dissemination of information irrespective of individual training or background. Of major emphasis was the selection of individuals to speak at the ASVA and other scientific and educational meetings. As the ASVA developed, publication of original research and review articles seemed in order. Bruce Heath accepted editorial responsibilities for manuscripts submitted for the ASVA journal. In 1971, John Thurmon chaired the Ad Hoc Committee to establish the American College of Veterinary Anesthesiologists (ACVA). The AVMA had established guidelines for the selection of founding-charter diplomat of specialty organizations. The Ad Hoc Committee requirements for charter diplomat status in a specialty included 10 years of active service in the specialty, significant publication, intensive training, and either being a recognized head of an anesthesiology program or spending a major portion of one's professional time in anesthesia or a closely related subject area. Seven members of the ASVA were found to meet these qualifications becoming the founding diplomats of the ACVA.

Between 1970 and 1975, the constitution and bylaws were drafted and formalized. In 1975, the AVMA Council on Education recommended preliminary approval of the ACVA and it was confirmed by the AVMA House of Delegates in that same year. Thus, the ACVA was officially established in North America. Of importance throughout this process were the insight and efforts of William Lumb and E. Wynn Jones. They greatly assisted in the establishment of the ACVA because of their sincere interest in the sound principles of veterinary anesthesiology. During this same period, several didactic texts had been published further establishing anesthesia as a stand-alone discipline and specialty within veterinary medicine. The first edition of this text, *Lumb and Jones' Veterinary Anesthesia*, was published in 1973, *Clinical Veterinary Anesthesia*, edited by Charles Short, was published in 1974, and the *Textbook of Veterinary Anesthesia*, edited by Larry Soma, was published in 1971.

During the late 1970s, many of the founding diplomats established residency training programs in their respective veterinary colleges. From 1975 to 1980, the ACVA developed continuing education programs, programs in self-improvement, and programs for testing and certification of new diplomates. Along with residency training programs, anesthesiology faculty positions were being created in a number of universities across North America. In 1980, an effort headed by then president Eugene Steffey sought and achieved the full accreditation of the ACVA by the AVMA.

During the past four decades, a number of additional organizations have promoted and contributed greatly to the advancement of veterinary anesthesia. They include the Association of

Veterinary Anaesthetists of Great Britain and Ireland (AVA) and the Veterinary Anesthesia and Surgery Association in Japan. These associations along with the ACVA were instrumental in organizing the first International Congress of Veterinary Anesthesiology with its stated objective of globally advancing the field of veterinary anesthesiology. The first International Congress was held in Cambridge, England, in 1982, and has been held continually triannually ever since at various locations around the world on nearly every continent.

Concurrently, during the latter decades of the 20th century, organized veterinary anesthesiology was being advanced in Western Europe. Veterinary anesthesiologists in the United Kingdom had established the Association of Veterinary Anaesthetists and awarded the Diploma of Veterinary Anaesthesia to those with advanced specialty training. Later, interest in board specialization became increasingly evident in the United Kingdom and many European countries, resulting in the establishment of the European College of Veterinary Anesthesiologists (ECVA). In order to better recognize the central role anesthesiologists have in providing and advancing pain management, both the ECVA and ACVA subsequently sought and were granted approval to incorporate the word 'analgesia' into their names. Thus, the colleges were renamed the European College of Veterinary Anesthesia and Analgesia (ECVAA) and the American College of Veterinary Anesthesia and Analgesia (ACVAA). Currently, a number of veterinary anesthesiologists are boarded by both the ACVAA and ECVAA with both organizations recognizing the legitimacy of either credential, allowing residency training programs supervised by ACVAA diplomats to qualify candidates to sit the ECVAA Board Exam and vice versa. For further information concerning the early history of veterinary anesthesia, the reader is referred to additional sources [11–14].

The establishment of the ACVAA and the ECVAA has helped to advance veterinary anesthesia and pain management on a global scale through their efforts to promote research, create knowledge and enhance its dissemination via annual scientific meetings and publications. The ACVAA and ECVAA have as their official scientific publication the *Journal of Veterinary Anaesthesia and Analgesia*, which also serves as the official publication of the International Veterinary Academy of Pain Management (IVAPM).

During the early 2000s, in an effort to improve out-reach to practitioners interested in humane care and to increase pain management awareness and continuing education programs for practicing veterinarians, the IVAPM was initially conceived of at the annual Veterinary Midwest Anesthesia and Analgesia Conference (VMAAC) Scientific Meeting. The organization's stated mission was to advance the multidisciplinary approach to pain management within the wider veterinary community and was supported by an ongoing academic–pharmaceutical industry partnership, the Companion Animal Pain Management Consortium, led by ACVAA diplomats Charles Short (president of the original ASVA), William Tranquilli, and James Gaynor. Appropriately, the first President-Elect of the IVAPM was the then current President of the ACVA, Peter Hellyer. Interestingly, at the time of this writing (early 2014), the current IVAPM President-Elect, Bonnie Wright, continues to represent the legacy of ACVAA leadership in the field of veterinary analgesia and pain management.

Indeed, alleviating animal pain and suffering is an increasingly important and defining issue for 21st century veterinary medicine.

Today, academic and private practice anesthesiologists, practitioners, veterinary technicians, research and industry veterinarians, and animal scientists alike are increasingly working together through organizations such as the ACVAA, ECVAA, IVAPM, AVA, AVTA, and others, toward the common goals of creating new knowledge, coordinating educational programs, and advancing veterinary anesthesia, analgesia, and pain management.

Anesthesiologist defined

A boarded *anesthesiologist* is a person with a doctoral degree who has been certified by either the ACVAA or ECVAA and legally qualified to administer anesthetics and related techniques [15]. The term *anesthetist* has more variable meaning because in some European countries an anesthetist is equivalent to an anesthesiologist, but in North America and many other countries anesthetist refers to a person who administers anesthetics who is not board certified or possibly not a physician or veterinarian. Perhaps the most appropriate way to define a *veterinary anesthesiologist* is by recognizing that the veterinarian has been extensively trained and supervised by either ACVAA or ECVAA diplomats and credentialed by a veterinary certifying anesthesia and analgesia specialty examination (i.e., either the ACVAA or ECVAA Certifying Board Exam) whose expertise consists of anesthetic and analgesic delivery and risk management across a wide array of species and medical circumstances.

Early conceptual stages of anesthesia

Throughout the early years of anesthetic administration (diethyl ether) to human and veterinary patients alike, the assessment of anesthetic depth was a learned skill, appreciated most fully by individuals with much experience and the courage to learn from trial and error. John Snow was the first physician to attempt to classify the depth of anesthesia based on observation of the patient [16]. Teaching new anesthetists how much anesthetic to administer required close oversight by an experienced person. This system became strained during periods of high demand for anesthetists such as was encountered during the First World War.

Dr Arthur Guedel was a physician from Indianapolis, Indiana, who served in the First World War. One of his tasks was to train orderlies and nurses to administer diethyl ether to wounded soldiers. Guedel thus developed guidelines through the use of a wall chart that could be used by anesthetists to gauge the depth of anesthesia (Table 1.1) [17].

While Guedel's original observations were made in human patients anesthetized with diethyl ether, they were subsequently adapted for use with other inhalant anesthetics such as halothane. Four progressive stages of anesthesia beginning at its initial administration and ending at near death were characterized. Within stage 3 there are three or four sub-classifications listed (Box 1.1). These planes of anesthesia represent the progressive central nervous system depression that can be observed while a patient is within a surgical depth of anesthesia.

Modern anesthetic techniques seldom utilize only inhalant anesthesia, which has led to less reliance on Guedel's classification. Incorporation of other drugs into balanced anesthetic techniques (e.g., antimuscarinics and dissociative anesthetics)

Table 1.1 Characteristics of the stages of general anesthesia.

Stage of Anesthesia		Plane			
		I	II	III	IV
System Affected Characteristic Observed		1	2	3	4
		Light	Medium	Deep	
Cardiovascular	Pulse ^a	Tachycardia	Progressive bradycardia		Weak or imperceptible
	Blood pressure ^a	Hypertension	Normal	Increasing hypotension	Shock level
	Capillary refill	1 s or less		Progressive delay	3 s or longer
	Dysrhythmia probability	+++	+++	++	+++
Respiratory	Respiratory rate ^a	Irregular or increased	Progressive decrease		Slow irregular
	Respiratory depth ^a	Irregular or increased	Progressive decrease		Irregular
	Mucous membrane, skin color	Normal			Cyanosis
	Respiratory action	May be breathholding	Thoracoabdominal, abdominal		Diaphragmatic
	Cough reflex	++++	+++	+	Lost
	Laryngeal reflex	++++	May vocalize	Lost	
	Intubation possible	No	Yes		
Gastrointestinal	Salivation	++++	+++	+	Diminished absent, except in ruminants
	Oropharyngeal reflex	++++	+++	+	Lost
	Vomition probability	+++	+++	+	Very slight
	Reflux (regurgitation) potential	None		Increases with relaxation	
	Tympany (rumen, cecum)	None		Potential increases with duration of anesthesia	
Ocular	Pupils	Dilated	Normal or constricted, progressive dilation		Acutely dilated
	Corneal reflex	Normal	+++	Diminishes, lost (horses may persist)	Absent
	Lacrimation	Normal	+++	+	Diminishes, absent
	Photomotor reflex	Normal	+++	+	Diminishes, absent
	Palpebral reflex	Normal	+++	+	Diminishes, absent
	Eyeball position	Normal	Variable	Ventromedial in dogs and cats or central	
	Nystagmus	++++	Especially horses and cows		+
Musculoskeletal	Jaw tone	++++	++++	Decreased, minimal	Lost
	Limb muscle tone	++++	++++	Decreased, minimal	Lost
	Abdominal muscle tone	++++	++++	++	Decreased, minimal
	Sphincters (anus, bladder)	May void		Progressive relaxation	Control lost
Nervous	Sensorium	+++	+	Lost	
	Pedal reflex	++++	++++	Decreased	Absent
	Reaction to surgical manipulation	++++	++++	+	None

^aSurgical stimulation causes increased heart rate, blood pressure and respiratory rate via autonomic responses that persist in plane 2. Vagal reflexes due to visceral traction persist in plane 3.

+ to ++++ = degree present.

greatly influence the reflexive and autonomic responses of the patient. In light of this, a greater reliance on monitoring patient physiologic parameters such as blood pressure, respiration, and neuromuscular tone has become common. Use of electroencephalographic monitoring of CNS activity (e.g., bispectral index monitoring) is currently of great interest and increasing in clinical application to insure adequate anesthetic depth for surgical procedures. Interestingly, a comparison of bispectral index

monitoring with Guedel's classic signs for anesthetic depth in humans anesthetized with diethyl ether has a relatively good correlation (Fig. 1.1) [18]. Nevertheless, and despite the incorporation of many new monitoring modalities in daily practice, the anesthetist should continue to have some understanding of the correlation of changing physical signs with anesthetic depth progression. Thus, Guedel's early observational classification will likely continue to have relevancy.

Box 1.1 Stages of anesthesia observed during inhalant anesthesia.

Stage I. The stage of voluntary movement is defined as lasting from initial administration to loss of consciousness. Some analgesia may be present in the deeper phases of this stage. Excited, apprehensive animals may struggle violently and voluntarily hold their breath for short periods. Epinephrine release causes a strong, rapid heartbeat and pupillary dilation. Salivation is frequent in some species, as are urination and defecation. With the approach of stage II, animals become progressively ataxic, lose their ability to stand, and assume lateral recumbency.

Stage II. The stage of delirium or involuntary movement. As the CNS becomes depressed, patients lose all voluntary control. By definition, this stage lasts from loss of consciousness to the onset of a regular pattern of breathing. As a result of anesthetic depression of the CNS, reflexes become more primitive and exaggerated. Patients react to external stimuli by violent reflex struggling, breath holding, tachypnea, and hyperventilation. Continued catecholamine release causes a fast, strong heartbeat, cardiac arrhythmias may occur, and the pupils may be widely dilated. Eyelash and palpebral reflexes are prominent. Nystagmus commonly occurs in horses. During this stage, animals may whine, cry, bellow, or neigh, depending on the species concerned. In some species, especially ruminants and cats, salivation may be excessive; in dogs, cats, and goats, vomiting may be evoked. The larynx of cats and pigs is very sensitive at this stage, and stimulation may cause laryngeal spasms.

Stage III. The stage of surgical anesthesia is characterized by unconsciousness with progressive depression of the reflexes. Muscular relaxation develops, and ventilation becomes slow and regular. Vomiting and swallowing reflexes are lost.

In humans, this stage has been further divided into planes 1–4 for finer differentiation. Others have suggested the simpler classification of light, medium, and deep. Light anesthesia persists until eyeball movement ceases. Medium anesthesia is characterized by progressive intercostal paralysis, and deep anesthesia by diaphragmatic respiration. A medium depth of unconsciousness or anesthesia has traditionally been considered a light plane of surgical anesthesia (stage III, plane 2) characterized by stable respiration and pulse rate, abolished laryngeal reflexes, a sluggish palpebral reflex, a strong corneal reflex, and adequate muscle relaxation and analgesia for most surgical procedures. Deep surgical anesthesia (stage III, plane 3) is characterized by decreased intercostal muscle function and tidal volume, increased respiration rate, profound muscle relaxation, diaphragmatic breathing, a weak corneal reflex, and a centered and dilated pupil.

Stage IV. Extreme CNS depression. Respirations cease and the heart continues to beat for only a short time. Blood pressure is at the shock level, capillary refill of visible mucous membranes is markedly delayed, and the pupils are widely dilated. Death quickly intervenes unless immediate resuscitative steps are taken. If the anesthetic is withdrawn and artificial respiration is initiated before myocardial collapse, these effects may be overcome and patients will go through the various stages in reverse.

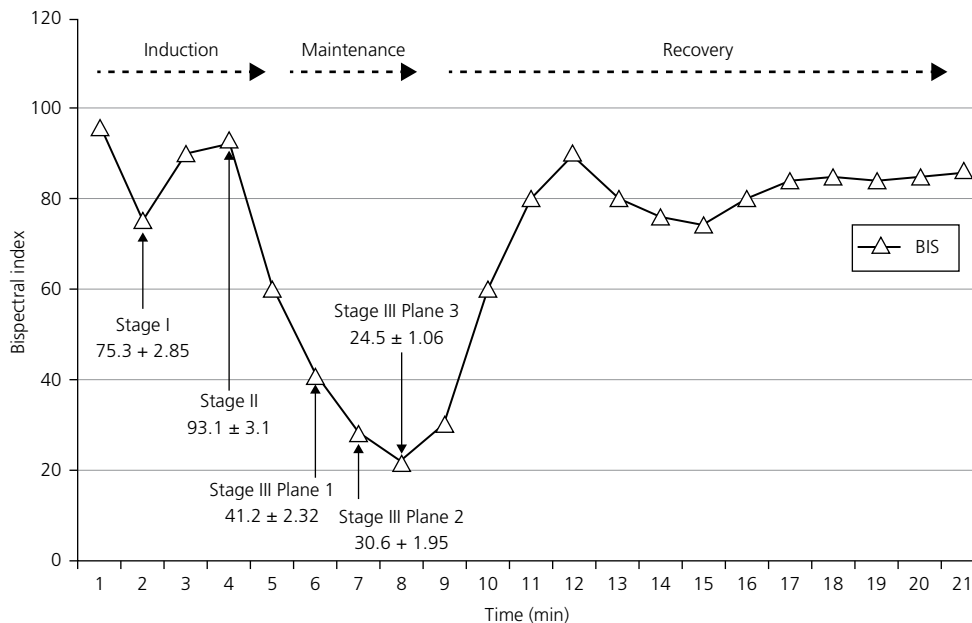


Figure 1.1 Bispectral index (BIS) values under various stages of ether anesthesia (mean \pm SD). Source: [18]. Reproduced with permission of Lippincott Williams & Wilkins.

Classification of anesthesia

The diverse uses for anesthesia (as it relates to immobilization, muscle relaxation, and antinociception) and the requirements peculiar to species, age, and disease state necessitate the use of a variety of drugs, drug combinations, and methods. Anesthetic technique is often classified according to the type of drug and/or method/route of drug administration:

1 Inhalation: Anesthetic gases or vapors are inhaled in combination with oxygen.

2 Injectable: Anesthetic solutions are injected intravenously, intramuscularly, and subcutaneously. Other injectable routes include intrathoracic and intraperitoneal. These last two routes are not generally recommended.

3 Total intravenous anesthesia (TIVA), partial intravenous anesthesia (PIVA) and targeted controlled infusion (TCI): Anesthetic techniques that utilize intravenous infusion of one or more drugs to produce a suitable anesthetic state. Some automated infusion systems are available that allow input of patient parameters and

pharmacokinetic information for specific drugs and allow the anesthesiologist to target a predetermined plasma drug concentration (TCI).

- 4 *Oral or rectal*: These routes are ordinarily used for liquid anesthetics, analgesics, or suppositories. There is often a greater degree of inter-species and inter-individual variability in the dose–response relationship of orally administered drugs due to differences in absorption and first-pass hepatic metabolism.
- 5 *Local and conduction*: Anesthetic drug is applied topically, injected locally into or around the surgical site (field block), or injected around a large nerve trunk supplying a specific region (conduction or regional nerve block). In the last instance, the injection may be perineural (nerve block) or into the epidural or subarachnoid space.
- 6 *Electronarcosis, electroanesthesia, or electrosleep*: Electrical currents are passed through the cerebrum to induce deep narcosis. Even though there have been successful studies, this form of anesthesia has never gained popularity and is rarely used in veterinary practice. Electronarcosis should not be confused with the inhumane practice of electroimmobilization.
- 7 *Transcutaneous electrical nerve stimulation (TENS, TNS, or TES)*: Local analgesia is induced by low-intensity, high-frequency electric stimulation of the skin through surface electrodes. TENS has many similarities to electroacupuncture.
- 8 *Hypnosis*: A non-drug-induced trance-like state sometimes employed in rabbits and birds.
- 9 *Twilight anesthesia*: A state of heavy sedation where the patient is still conscious, but cooperative, and has limited or no recall (amnesia). This technique is popular for outpatient anesthesia in human medicine for diagnostic procedures and for minor surgical procedures when combined with local anesthetics and additional analgesic drugs. *Twilight anesthesia* is a term in common use by laypeople to connote heavy sedation and does not refer to a specific anesthetic procedure or technique.
- 10 *Acupuncture*: A system of therapy using long, fine needles to induce analgesia. Additional modalities of acupuncture point stimulation have been utilized, including mechanical and electrical stimulation.
- 11 *Hypothermia*: Body temperature is decreased, either locally or generally, to supplement insensitivity and decrease anesthetic drug requirement, and reduce metabolic needs. It is primarily used in neonates or in patients undergoing cardiovascular surgery.

Environmental considerations

Concerns about potential adverse effects associated with the use of anesthetic drugs fall into three general categories. The first is patient-experienced adverse drug reactions, which can be classified into seven types: dose-related (Augmented or type A), non-dose-related (Bizarre or type B), dose-related and time-related (Chronic or type C), time-related (Delayed or type D), withdrawal (End of use or type E), failure of therapy (Failure or type F), and genetic reactions (type G) [19]. Specific patient-experienced adverse drug reactions are reviewed in other areas of this text.

A second type of adverse effect is experienced by health and veterinary care providers exposed to anesthetic drugs and gases during the performance of their daily tasks. Acute exposure through accidental needle penetration or through accidental spillage of drugs will always be a risk. Many employers have standard operating procedures in place, instructing employees how to limit their exposure

and how to proceed if exposure occurs. Chronic workplace exposure to low levels of inhalant anesthetic agents has been a concern since their use began and, although studied repeatedly, questions still exist about the relative risk of toxicity such as infertility, miscarriage, cancer, and other chronic health problems. Part of the difficulty in determining safe levels of exposure is related to the apparently low incidence of adverse effects and the potentially long lag period between exposure and expression of toxicity. Usually the question is approached through large epidemiological studies of healthcare providers that are administering anesthetics. This introduces many confounders such as provider age, agents in use, coexisting health problems, and measurement of actual provider exposure, which may make interpretation and generalization of results problematic. Occupational exposure to inhalant anesthetics is addressed in Chapter 16, Inhalant Anesthetics.

The third type of anesthetic adverse effect is environmental. Historically, drug development and clinical use of anesthetic agents did not consider the resources consumed to produce drugs, or their ultimate fate once eliminated by the patient. Of the inhalant anesthetics in clinical use, desflurane is responsible for the largest greenhouse gas emission (both carbon dioxide and halogenated compounds) during its lifecycle. It is approximately 15 times that of isoflurane and 20 times that of sevoflurane on a per MAC-hour basis. The concurrent use of nitrous oxide to facilitate delivery of inhalant anesthetics further increases emissions. The impact of the contemporary inhalant anesthetics on ozone depletion has also been studied [20]. Although these agents do have some potential for ozone depletion, their relative contribution is low and the impact on global warming through this mechanism is minor. For all of the inhalation anesthetics, their eventual release as waste anesthetic gases into the atmosphere is the largest contributor to their greenhouse gas footprint and global warming potential.

Propofol's impact on greenhouse gas emission is much smaller, by nearly four orders of magnitude, than that of desflurane or nitrous oxide. The greenhouse gas emission associated with propofol and many other injectable anesthetic drugs is primarily related to their production and consumption of fossil fuels needed to manufacture and deliver the drugs [21,22].

References

- 1 Short CE. The management of animal pain: where have we been, where are we now, and where are we going? *Vet J* 2003; **165**: 101–103.
- 2 Heavner JE. Veterinary anesthesia update. *J Am Vet Med Assoc* 1983; **182**: 30.
- 3 Winters WD, Ferrer AT, Guzman-Flores C. The cataleptic state induced by ketamine: a review of the neuropharmacology of anesthesia. *Neuropharmacology* 1972; **11**: 303–315.
- 4 Askitopoulou H, Ramoutsaki IA, Konsolaki E. Analgesia and anesthesia: etymology and literary history of related Greek words. *Anesth Analg* 2000; **91**(2): 486–491.
- 5 International Association for the Study of Pain. *IASP Taxonomy*. <http://www.iasp-pain.org/Education/Content.aspx?ItemNumber=1698> (accessed 15 September 2014).
- 6 Thurmon JC, Benson GJ. Anesthesia in ruminants and swine. In: Howard JL, ed. *Current Veterinary Therapy*, vol. 3. Philadelphia: WB Saunders, 1993; 58–76.
- 7 Jackson CT. Etherization of Animals. *Report of the Commissioner of Patents for the Year of 1853*. Washington, DC: Beverly Tucker, Senate Printer, 1853, 59.
- 8 Dadd GH. *The Modern Horse Doctor*. Boston: JP Jewett, 1854.
- 9 Keys TE. The development of anesthesia. *Anesthesiology* 1942; **3**: 11–23.
- 10 Stevenson DE. The evolution of veterinary anesthesia. *Br Vet J* 1963; **119**: 477.
- 11 Clark AJ. Aspects of the history of anesthetics. *Br Med J* 1938; **ii**: 1029.
- 12 Smithcors JE. The early use of anesthesia in veterinary practice. *Br Vet J* 1957; **113**: 284.
- 13 Lee JA. *A Synopsis of Anesthesia*, 4th edn. Baltimore: Williams & Wilkins, 1959.
- 14 Miller RD. *Anesthesia*, 2nd edn. New York: Churchill Livingstone, 1986.
- 15 Medical Dictionary. *Medical Dictionary, Medical Terminology*. <http://www.medical-dictionary.com/medicaldictionary.php> (accessed 1 December 2012).

- 16 Snow J. *On the Inhalation of the Vapor of Ether in Surgical Operations*. London: Churchill, 1847.
- 17 California Pacific Medical Center. <http://www.cpmc.org/professionals/hslibrary/collections/guedel/> (accessed 15 September 2014).
- 18 Bhargava AK, Setlur R, Sreevastava D. Correlation of bispectral index and Guedel's stages of ether anesthesia. *Anesth Analg* 2004; **98**(1): 132–134.
- 19 Edwards IR, Aronson JK. Adverse drug reactions: definitions, diagnosis, and management. *Lancet* 2000; **356**(9237): 1255–1259.
- 20 Langbein T, Sonntag H, Trapp D, *et al*. Volatile anaesthetics and the atmosphere: atmospheric lifetimes and atmospheric effects of halothane, enflurane, isoflurane, desflurane and sevoflurane. *Br J Anaesth* 1999; **82**(1): 66–73.
- 21 Sherman J, Le C, Lamers V, Eckelman M. Life cycle greenhouse gas emissions of anesthetic drugs. *Anesth Analg* 2012; **114**(5): 1086–1090.
- 22 Ryan SM, Nielsen CJ. Global warming potential of inhaled anesthetics: application to clinical use. *Anesth Analg* 2010; **111**(1): 92–98.

2

Anesthetic Risk and Informed Consent

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Anesthetic risk assessment

Perioperative assessment of anesthetic risk is a valuable exercise in order to minimize complications and optimize anesthetic safety. A number of studies have been published in relation to anesthetic morbidity and mortality in both small and large animals, and based on this evidence improved recognition of the risks of anesthesia and those patients that require greatest care and preoperative management could help improve standards of veterinary anesthesia and patient outcome.

General overview – preoperative patient risk assessment

Patient health assessment

The preoperative assessment of an animal's health status is valuable to acknowledge preanesthetic risks, to identify management priorities and to advise clients appropriately prior to anesthesia and surgery. Health status has been consistently reported to be associated with anesthetic death in humans and in the spectrum of species commonly seen in veterinary anesthesia. Increased American Society of Anesthesiologists (ASA) grade [1,2] (see Table 2.1) has been associated with an increased risk of death in a number of small animal anesthetic studies [3–12], in horses [13,14], and in human anesthesia [15–34].

Anesthetic agents cause cardiopulmonary depression and the presence of pre-existing pathology is likely to predispose to greater anesthetic-induced physiologic disturbance [35]. Disturbances of major body systems will make the patient less tolerant of physiologic depression induced by anesthesia. Pre-existing cardiopulmonary pathology is particularly relevant in the immediate preoperative period, as anesthetic-related mortality is likely to involve respiratory or cardiovascular compromise, and most anesthetics depress one or both systems at clinical levels of anesthesia [35].

Hematologic and biochemical abnormalities may also be a significant consideration. In particular, anemia will reduce oxygen-carrying capacity and predispose to hypoxia, and hypoproteinemia has been theorized to increase the response of the patient to highly protein-bound drugs and result in relative overdose [35]. Renal disease is also important, particularly if dehydration or uremia is present, as under these conditions the renal system will have a lower tolerance to anesthesia and the patient may be more sensitive to some anesthetics and perioperative drugs such as non-steroidal anti-inflammatory agents. Neurologic disease may be relevant with respect to the occurrence of postoperative seizures, increased sensitivity to anesthetics, and when cardiopulmonary function is affected, e.g., medullary pathology can depress ventilation and cardiovascular function. Additionally, liver and endocrine disease may influence the response to anesthesia, with diabetes mellitus and potential intraoperative cellular changes in glucose concentrations being particularly relevant [36].

Hence some form of physical health status assessment is an important preanesthetic consideration. Most frequently, ASA grade [1,2] has been described. However, the repeatability and agreement between observers of such scoring systems have been questioned and evidence suggests that inter-observer agreement in ASA health status classification is poor in veterinary anesthesia [37]. Other assessment systems exist in human medicine, including the Acute Physiology and Chronic Health Evaluation (APACHE), and the Physiological and Operative Severity Score for the enUmeration of Mortality and morbidity (POSSUM) and in pediatric practice the Neurological, Airway, Respiratory, Cardiovascular and Other (NARCO) score, and all were observed to predict perioperative risk [38–40]. However, these systems are complex, require more time to complete, and have yet to be evaluated for agreement between observers in a veterinary context. Hence, at present, there appears

Table 2.1 Classification of physical status^a.

Category	Physical Status	Possible Examples of This Category
1	Normal healthy patients	No discernible disease; animals entered for ovariectomy, ear trim, caudectomy, or castration
2	Patients with mild systemic disease	Skin tumor, fracture without shock, uncomplicated hernia, cryptorchidectomy, localized infection, or compensated cardiac disease
3	Patients with severe systemic disease	Fever, dehydration, anemia, cachexia, or moderate hypovolemia
4	Patients with severe systemic disease that is a constant threat to life	Uremia, toxemia, severe dehydration and hypovolemia, anemia, cardiac decompensation, emaciation, or high fever
5	Moribund patients not expected to survive 1 day with or without operation	Extreme shock and dehydration, terminal malignancy or infection, or severe trauma

^aThis classification is the same as that adopted by the American Society of Anesthesiologists.

to be little consensus as to the optimal method of patient health status assessment for consistent and efficient classification across observers and caution should be exercised in over-interpreting individual health status assessments. Nonetheless, there is a body of evidence that highlights that sicker patients are more likely to die perioperatively and therefore some form of preoperative patient assessment would be advisable to distinguish sick from healthy patients, to identify those at greater risk, and to manage patients appropriately in order to try to minimize risk prior to, during, and after anesthesia.

Preanesthetic blood testing

Given the fact that organ dysfunction and various pathologic conditions such as anemia or hypoproteinemia may contribute to increased anesthetic morbidity or mortality, it would seem sensible to make every effort to detect these prior to general anesthesia. For this reason, routine preanesthetic blood screening is commonly recommended by many veterinary practitioners and, indeed, some anesthesia specialists. However, although there is no doubt that prior biochemical and hematologic analyses are of definite value in certain patient groups, the question remains as to whether their use can be justified for every patient, in particular healthy animals undergoing elective procedures.

An internet search for 'Preanesthetic blood screening in animals' (<https://www.google.com>, accessed August 2013) returned over six million 'hits,' of which a substantial proportion appeared to be veterinary practices each detailing their reasons and prices for carrying out such a procedure; interestingly, the search term returned virtually no scientific papers relating to the practice. In addition, as with much information to be found on the internet, many of the relevant web pages providing advice on the subject were written by people with no apparent scientific background or credentials for discussing such a topic, with the majority of these being pet owner discussion forums. Although there may be no genuine scientific or clinical background behind these types of discussion groups, they almost certainly help perpetuate the 'need' for ubiquitous preanesthetic blood testing, but given that many veterinary professionals also recommend its routine use, it obviously cannot all be dependent on owner perceptions. So, is there actually a sound rationale upon which the need for preanesthetic biochemical and hematologic sampling is based?

There are numerous studies in human anesthesia now questioning the necessity for preanesthetic laboratory testing in healthy patients [41–43], with each of these demonstrating that – for subjects with no demonstrable abnormalities on the basis of history and clinical examination – there appears to be no reduction in perianesthetic complications if prior blood sampling has been carried out. The UK National Institute for Health and Care Excellence (NICE) gathers evidence from a variety of sources and then produces recommendations for human clinicians for various medical and surgical interventions. In terms of preanesthetic blood testing, NICE subdivides its recommendations based on both the age of the patient and the 'grade' of surgery the subject is undergoing, with a grading system (from least to most invasive) of 1–4 (separate grading systems are used for those undergoing neurologic or cardiovascular surgery). There is a huge number of different surgeries allocated to each grade. Examples of grade 1 procedures include surgery on the external nose or nasal septum, or on the prepuce; grade 2 procedures include tonsillectomy or inguinal hernia repair; grade 3 total mastectomy or hysterectomy and grade 4 total hip replacement or renal transplantation [44]. Based on this system, NICE recommends a full blood count only in those humans over 60 years old when undergoing moderate to major surgical procedures (surgical severity grading of ≥ 2), in all adults undergoing major surgery (surgical severity grade ≥ 3), or in those with severe renal disease [44]. Similarly, recommended biochemical testing (urea, creatinine, and electrolytes) is only advocated in patients older than 60 years of age and undergoing a procedure of surgical severity ≥ 3 , for all adults having surgery of severity grade 4 (the maximum grade), or in the presence of any renal disease or severe cardiovascular disease [44].

The recommendations for preanesthetic blood screening are even more restrictive in human pediatric patients (<less than 16 years old). If the individual is ASA 1, no routine preanesthetic testing is advised regardless of the grade of surgery being undertaken, the only exceptions being if the child is undergoing either neurologic or cardiovascular procedures [44]. Surprisingly, standard guidelines do not appear to have been published for children who are \geq ASA 2. The discrepancy between the sampling recommendations for human pediatric patients and adults probably relates to the increased incidence of comorbidities in the latter. As a result of the NICE recommendations, the guidelines of the Association of Anaesthetists of Great Britain and Ireland (AAGBI) [45] for human anesthesia conclude: 'Routine pre-operative investigations are expensive, labour intensive and of questionable value, especially as they may contribute to morbidity or cause additional delays due to spurious results.'

Aside from the issue of erroneous results impacting on the efficiency of case throughput, it is also important to remember that the reference ranges established for most laboratory tests incorporate only approximately 80% of the population, i.e., around one in five animals that are perfectly healthy will return laboratory results that are outside the 'normal' range, which may then lead to further unnecessary investigations being carried out, in addition to delaying the planned procedure. Hence it is important to interpret carefully test results obtained and to view them as part of the overall assessment of the patient.

The AAGBI also takes the view that history and examination performed by appropriately trained and competent personnel remain the most efficient and accurate way of initially detecting significant morbidity: 'Thus, it is important that, where preanaesthetic blood screening is carried out, it is seen as an adjunct to a full

clinical examination, rather than an alternative.' While this is undoubtedly the case in both veterinary and human anesthesia, the results from human studies relating to preanesthetic blood screening of healthy patients may not be directly applicable to animals. This is because the majority of humans are both cognitive and verbal, and are able to self-report health issues. Veterinary clinicians, on the other hand, obtain the relevant health information by proxy (the owner), which may mean that important details are not identified. Thus, it is possible that a higher incidence of abnormalities may be detected on preanesthetic screening of animals than has been reported for humans.

Given that the consensus opinion from human anesthesia seems to be that preanesthetic blood sampling appears to be justifiable only in 'sicker' patients, and that healthy individuals undergoing elective procedures do not benefit from this practice, what recommendations should be put in place for veterinary anesthesia? There appear to be at least three studies relating to the validity of routine preanesthetic blood screening in animals. Toews and Campbell [46] performed a complete blood count in 102 horses undergoing cryptorchidectomy and then determined whether any abnormalities detected impacted on the risk of surgical complications. They found that 55 animals had results outside the reference range for at least one hematologic parameter, but there was no correlation between those demonstrating abnormal values and the likelihood of either intra- or postoperative surgical complications, nor did these abnormalities dictate alterations in patient management. Alef and colleagues [47] analyzed results from over 1500 dogs undergoing anesthesia at the University of Leipzig, and reported that if no potential issues were identified in either the animal's history or clinical examination, 'the changes revealed by preoperative screening were usually of little clinical relevance and did not prompt major changes to the anesthetic technique.' They concluded that preanesthetic blood screening is, therefore, unlikely to yield additional important information in most cases. However, the same study also documented that of those dogs where the history and clinical examination would not normally have resulted in preanesthetic laboratory testing being performed at their institution (equivalent to 84% of the dogs recruited), 8% demonstrated biochemical or hematologic abnormalities that would have reclassified them as a higher ASA status, even if this may not necessarily have altered the anesthetic protocol. In addition, they also identified that surgery would have been postponed due to the laboratory findings in 0.8% of these dogs where preanesthetic blood screening would not usually have been performed, while 1.5% would have received additional preanesthetic therapy. Although the authors concluded that only 0.2% of dogs in the study would have required an alteration to their proposed anesthetic protocol based on the biochemical or hematologic results, the implication that undiagnosed pathology may be detected prior to anesthesia using 'routine' screening may have implications for whether the owner decides to proceed with anesthesia/surgery, and may also alter the expected prognosis for the animal. Thus, despite the fact that preanesthetic biochemical and hematologic testing may not alter how the subsequent anesthetic is actually performed in most animals, it may in reality be the deciding factor as to whether the procedure goes ahead.

Given that advancing age is one component impacting on the NICE recommendations regarding preanesthetic blood screening in humans, it would be useful to know whether abnormal results are more likely to be detected in this same patient group in veterinary anesthesia, and any potential impact that this may have. In this regard, Joubert [48] assessed whether hematologic and biochemical

analyses were of value in geriatric dogs (>7 years of age) presented for anesthesia. Of the 101 dogs recruited to the study, 30 new diagnoses (e.g., neoplasia, hyperadrenocorticism) were made on the basis of the blood sample, with 13 animals not undergoing general anesthesia as a result of the new diagnosis. However, similarly to the conclusions of the study by Alef and colleagues [47], Joubert [48] suggested that although preanesthetic screening had revealed the presence of subclinical disease in almost 30% of the dogs in the study, and that screening of geriatric patients is important, 'the value of screening before anesthesia is perhaps more questionable in terms of anesthetic practice but it is an appropriate time to perform such an evaluation.' In other words, although preanesthetic blood testing may be of value in uncovering undiagnosed pathology in geriatric patients, there was little evidence that what was detected would actually impact on either how the subsequent anesthetic was managed, or the overall outcome from it. However, this study did identify that over 10% of the dogs had their anesthesia cancelled due solely to the findings of the preanesthetic blood screening, which is obviously of significance.

Interestingly, and somewhat in contrast to the previous studies, work within the Confidential Enquiry into Perioperative Small Animal Fatalities (CEPSAF) highlighted a reduction in risk when preoperative bloods were taken in higher ASA grade patients. CEPSAF was a multicenter study undertaken in the UK between 2002 and 2004 and involved over 100 practices and data from approximately 200 000 dogs and cats [49]. When analyzing risk factors for anesthetic death in sick dogs (ASA 3–5), having a preoperative blood test was associated with reduced odds of death, particularly in ASA grade 4–5 dogs [50]. This association was not detected in the overall analyses where ASA grade 1–5 dogs were considered together or in cats, but does suggest that preoperative biochemistry and hematology are most likely to be merited in the sicker animals that are anesthetized.

Thus, based on the evidence from human anesthesia, and from a smaller number of published veterinary studies, there would appear to be negligible benefit to apparently healthy animals (ASA 1) of biochemical or hematologic screening prior to anesthesia in terms of either anesthetic risk reduction or alteration of the anesthetic protocol; however, given that a significant percentage of animals may have the procedure cancelled based on the results of these tests (due either to a worsened prognosis or the need for further treatment prior to anesthesia), this may counterbalance the preceding argument. Overall, the requirement for preanesthetic blood screening in ASA 1 animals is likely to remain a contentious issue, with valid arguments both for and against.

The situation in animals that are ASA 2 or greater, however, is probably more clear cut, with the published veterinary studies providing some justification that preanesthetic screening may be of value in terms of potentially altering anesthetic management and outcome.

Aside from the impact (or lack thereof) that preanesthetic screening may have on the subsequent conduct of anesthesia and ultimate outcome for veterinary patients, there is perhaps another factor that may require consideration, namely that of potential litigation. It seems that an increasing number of clients are willing (sometimes overly so) to 'point the finger of blame' at the veterinarian when things go wrong in relation to anesthesia, even when in many cases this may be completely unjustified. Hence the genuine reason why many veterinary practices carry out routine preanesthetic screening may be more to do with 'covering one's back' rather than providing the ability to alter anesthetic management suitably if

abnormalities are actually detected. It is impossible to say what the legal system may make of a healthy animal undergoing an elective procedure that dies during anesthesia where no preoperative blood sampling had been performed, but based on the recommendations from human anesthesia and the lack of evidence of any benefit in the few veterinary studies that have been carried out, it would appear difficult for them to state that preanesthetic biochemical or hematologic screening is a basic standard of care. Given that there is a more limited evidence base for 'sicker' animals, it may be considered wise to perform preanesthetic screening in patients of ASA 2 or above, from both standard of care and litigation points of view.

Morbidity and mortality

Nonfatal complications tend to occur more frequently than mortal events, although they have been less often documented in the veterinary literature. Reported small animal morbidity risks range from 2–10% [4,5,10,51]. Work in small and large animal anesthesia has acknowledged the difficulty of ensuring consistent detection and recording of morbid events in the practice setting [3,4,52,53]. Small animal practice standards of monitoring of anesthesia are often superficial [54–56] and, unless a given complication results in obvious patient disturbance, it may go unnoticed. Hence, in considering morbid complications, only major events, most likely to be consistently observed, that could contribute substantial physiologic disturbance and that could have the greatest impact on a patient (other than death) will be discussed here.

Small animal anesthesia morbidity

Small animal anesthesia morbidity studies have most frequently been veterinary teaching hospital based, with a few primary practice-based studies also reporting major non-fatal complications [3–5,10,51,56,57]. Conditions consistently described include respiratory, cardiovascular, renal, gastrointestinal, thermoregulatory, and neurologic complications.

Respiratory complications were observed in 0.54% of dog and 0.34% of cat anesthetics in a study of practitioners in Ontario, Canada, and included respiratory depression or apnea, respiratory distress, and difficulty with intubation (although the definitions of these were not stated) [4]. In a veterinary teaching hospital setting, similar respiratory complications were observed, but more often. Hypoventilation and hypercapnia (defined as partial pressure of arterial carbon dioxide or end-tidal carbon dioxide >55 mmHg) were reported in 1.3% and in 1 of 683 dogs and cats undergoing anesthesia, respectively, and hypoxemia (partial pressure of arterial oxygen <60 mmHg or hemoglobin arterial oxygen saturation <90%) was reported in 0.5% of dogs and occasionally airway compromise was also noted [51]. More recently in a Spanish veterinary school hospital, hypoventilation (defined as minute ventilation <100 mL/kg/min) was observed in over 60% and hypoxemia (defined as an $SpO_2 < 90\%$) in 16% of anesthetized dogs [57].

Cardiovascular compromise in small animals included the development of cardiac arrhythmias, notably bradycardia in 0.62% and 0.14% of dog and cat anesthetics in a primary practice setting, although the latter was classified as <60 beats/min and irregular or <50 beats/min and regular for both dogs and cats [4]. In contrast, in a teaching hospital setting, the most frequently recorded cardiovascular complications were hypotension (defined as systolic arterial pressure <80 mmHg or mean arterial pressure <60 mmHg and observed in 7% and 8.5% of dogs and cats, respectively), and cardiac arrhythmias (2.5% and 1.8% of dog and cats, respectively) [51].

Hosgood and Scholl [5,10] reported similar levels of arrhythmias in a teaching hospital environment, with 4% of dogs and 3.6% of cats exhibiting cardiac arrhythmias. The arrhythmias recorded included premature ventricular contractions, sick sinus syndrome, second-degree heart block, and ventricular tachycardia. Bradycardia (heart rate <50 bpm) was reported in approximately 36% and hypotension (mean arterial blood pressure <60 mmHg, or systolic arterial blood pressure <90 mmHg) in nearly 38% of dogs anesthetized at a veterinary school hospital in Spain [57].

Regurgitation was the most frequently documented perioperative gastrointestinal complication. The risk of regurgitation in dogs without pre-existing predisposing disease has been reported in some studies to be between 0.42 and 0.74% [58–60], whereas another report documented a substantially greater risk of regurgitation (5.5%) [61]. The variation in frequency across these studies likely reflects differences in procedures performed, premedication and anesthetic drugs and doses used, and the dog populations studied. The risk of gastroesophageal reflux, which may result in substantial esophageal mucosa injury, has been previously reported at a much higher level of 16–17% and even up to 27–60%, again depending on the animals studied and anesthetic drugs administered, suggesting that the risk of mucosal injury may be much greater than the proportion of patients where reflux is observed [58,59,61,62].

Hypothermia, where monitored, was a particularly common complication. In a veterinary teaching hospital study, 85% of dogs had a temperature recorded perioperatively of less than 37.3 °C and 51% of cats had a body temperature less than 35.0 °C during or after anesthesia [5,10]. Recent work in a veterinary university hospital in Spain highlighted perioperative hypothermia in over 70% of cats and 32% of dogs (body temperature <36.5 °C) [63,64].

Poor recoveries have also been documented, often recorded as prolonged return to consciousness, and these were seen in 0.14–0.18% of dog and cat anesthetics in one study [4]. A smaller number of dogs and cats exhibited complications including excitement in recovery, collapse, prolonged hypothermia, reduced consciousness after an apparently normal recovery, and renal failure [4]. Further, occasional case reports of perioperative blindness have been published, but there are limited data on the frequency of this complication relative to the number of animals anesthetized [65,66]. Interestingly, the use of a mouth gag was reported in 16 of 20 cats observed with postanesthetic cortical blindness, although data relating to denominator use of a mouth gag in general were not available, limiting the ability to conclude an association between the use of a gag or a procedure and the development of blindness [65].

Large animal anesthesia morbidity

A range of non-fatal complications have been reported, although information on their frequency in general equine populations is limited. Cardiovascular compromise, as reported in small animal anesthesia, is a major consideration in equine anesthesia. Hypotension and brady- and tachyarrhythmias have been described. In particular, second-degree atrioventricular block, atrial fibrillation, and ventricular premature contractions have all been reported [67]. Respiratory morbid complications have centered on hypoventilation and hypercapnia and hypoxemia, and these have frequently been reported as potential complications of equine anesthesia [67,68].

In contrast to small animal anesthesia, horses appear to demonstrate a wider range of postoperative complications, including fractures and soft tissue injury, myopathy, neuropathy, and myelopathy, and many result in death or euthanasia [67]. There are limited data

on the frequency of these events when non-fatal, although evidence of these complications resulting in mortality highlights their importance. Fractures have been reported intermittently and have often resulted in euthanasia. In the Confidential Enquiry into Perioperative Equine Fatalities (CEPEF), a multicenter prospective study of complications in equine anesthesia, fractures were estimated to be the cause of 25% of anesthetic deaths, myopathy 7%, and CNS complications 5.5% [53]. Similarly, in a single-center study in Kentucky (USA), fractures were the cause of 19% of deaths or euthanasias and neuropathy and myopathy 7% [69]. Other complications reported included postanesthetic colic, which in a multicenter study in the United Kingdom was estimated at approximately 5% of all anesthetized horses [70].

Mortality studies

Small animal anesthetic fatalities

Risks of anesthetic death

Mortality, in contrast to morbidity, has been more consistently observed and has been reported extensively in the veterinary literature. In small animal anesthesia, the risk of death has been documented over the last 50 years [71], and trends to reduction in risk over time have been reported (see Table 2.2). Referral center- and university-based studies generally have reported higher death risks due to the nature of their patients and procedures, whereas practice-based studies tended to reflect healthier populations and simpler procedures. Direct comparison of risks of death between studies has been limited by a number of factors, including variations in study case definitions, study populations, and procedures performed.

Initial institution-based studies from the United States documented a wide range of relatively high risks of mortality. An early study at the Angell Memorial Animal Hospital in Boston published risks of anesthetic death of 0.26% in dogs, 0.36% in cats, and 5% in other species [72]. Colorado State University reported higher risks

of 1.08% in dogs and 1.79% in cats between 1955 and 1957 [73], and the Wheatridge Animal Hospital (Colorado) reported anesthetic death risks of 0.23% in dogs and 0.40% in cats between 1960 and 1969 [73]. At a similar time, the University of Missouri Veterinary Hospital reported mortality risks of 0.8% in dogs and 0.53% in cats [73]. More recent referral center studies have reported lower risks of mortality, suggesting that outcomes have improved. Further work at Colorado State University documented risks of 0.43% in dogs and 0.26% in cats between 1979 and 1981 and 0.43% in dogs and 0.35% in cats between 1993 and 1994 [51,74]. Louisiana State University reported higher risks of perioperative death of 1.49% of dogs and 5.80% of cats at their institution between 1995 and 1996, although this related to all deaths, not just anesthetic-related mortality [5,10]. Work at the Royal Veterinary College in the United Kingdom reported an anesthetic-related mortality risk of 0.58% in dogs between 1999 and 2002 [6]. Based on the more recent work described above, the risk of anesthetic-related death in the referral setting would appear to be of the order of 0.25–0.60% in dogs and cats.

Work undertaken in small animal primary practice has generally documented lower risks of mortality than referral-based studies. An early practice-based study evaluated feline mortality in Scotland (United Kingdom) and published a risk of death of 0.31% in cats [75]. This was followed by a further survey of small animal anesthetic practice, undertaken in Vermont (United States), which reported the risk of death to be 0.11% and 0.06% in dogs and cats, respectively [76]. A similar study was undertaken in Finland in 1993 and reported a risk of death of 0.13% in small animals in general [77]. A more recent retrospective study evaluated mortality in a South African practice population in 1999 and estimated a mortality risk of 0.08% in dogs and cats [56], and a private veterinary clinic in France reported a risk of anesthetic death of 1.35% overall and 0.12% for healthy patients (ASA 1–2) [12]. The health status of the patients anesthetized in these studies was not always recorded, although it was likely to reflect relatively healthy animals and partly explains the generally lower risks reported.

The first prospective multicenter cohort study of small animal practice complications was undertaken between 1984 and 1986 in the United Kingdom [3]. Fifty-three practices were recruited, 41 881 anesthetics were recorded and anesthetic risks of death of 0.23% in dogs and 0.29% in cats were reported. For healthy patients (ASA grades 1–2, see Table 2.1), the death risks were 0.12% in dogs and 0.18% in cats, whereas in ill patients (ASA grades 3–5, see Table 2.1), over 3% of dogs and cats died perioperatively. Perioperative deaths in healthy patients (ASA 1–2), occurring during or shortly after surgery, were considered ‘primarily due to anesthesia’ unless an obvious surgical cause was present, whereas in sick patients (ASA 3–5), all deaths independent of cause were reported. This was followed by a further prospective multicenter cohort study of anesthetic mortality in small animal veterinary practice in Ontario, Canada [4]. During the 6 month study period, 8087 dogs and 8702 cats were anesthetized and 0.11% of dogs and 0.10% of cats had cardiac arrests and died. For healthy animals (ASA 1–2), the risks were 0.067% in dogs and 0.048% in cats, whereas for sick patients (ASA 3–5), 0.46% of dogs and 0.92% of cats died of a cardiac arrest. Only perioperative deaths within an unspecified follow-up period resulting from cardiac arrest were included.

The largest recent multicenter small animal practice-based study, the Confidential Enquiry into Perioperative Small Animal Fatalities (CEPSAF), was undertaken in the United Kingdom between 2002 and 2004 and 98 036 anesthetics and sedations were recorded in

Table 2.2 Summary risks of anesthetic death in dogs and cats published in primary practice and institutional studies.

Location [Ref.]	Year	Institution of Practice	Risk of Anesthetic Death (%)	
			Dog	Cat
Angell Memorial AH, Boston [72]	1946–50	Institution	0.26	0.36
CSU, Colorado [73]	1955–57	Institution	1.08	1.79
Wheatridge AH, Colorado [73]	1960–69	Institution	0.23	0.40
Univ. Missouri, VH [73]	1968–69	Institution	0.8	0.53
CSU, Colorado [74]	1979–81	Institution	0.43	0.26
CSU, Colorado [51]	1993–94	Institution	0.43	0.35
Louisiana State [5, 10]	1995–96	Institution	1.49	5.80
RVC, London [6]	1999–2002	Institution	0.58	–
Scotland [75]	1975	Practice	–	0.31
Vermont [76]	1989	Practice	0.11	0.06
UK [3]	1984–86	Practice	0.23	0.29
Ontario, Canada [4]	1993	Practice	0.11	0.10
Finland [77]	1993	Practice	0.13 in small animals	–
South Africa [56]	1999	Practice	0.08 in dogs and cats	–
UK [7]	2002–04	Practice	0.17	0.24
Spain [11]	2007–08	Practice	1.39 in dogs and cats	–
France [12]	2008–10	Practice	1.35 in dogs and cats	–

CSU=Colorado State University, AH=Animal Hospital, VH=Veterinary Hospital, RVC=Royal Veterinary College.

dogs and 79 178 in cats, across 117 participating centers [49]. Anesthetic- and sedation-related death was defined as perioperative death within 48 h of termination of the procedure, except where death was due solely to inoperable surgical or pre-existing medical conditions (i.e., anesthesia and sedation could not be reasonably excluded from contributing to the death). The risk of anesthetic- and sedation-related death was approximately 0.17% in dogs and 0.24% in cats (Tables 2.2 and 2.3). In healthy patients (ASA 1–2), the risks were 0.05% and 0.11% in dogs and cats, respectively, whereas in sick patients (ASA 3–5) over 1% of dogs and cats died (Table 2.4). Rabbits were the third most commonly anesthetized species in practice but the risks of anesthetic-related death were substantially higher, with 0.73% of healthy rabbits and 7.37% of sick rabbits dying. The risks in other small animal species were also high, between 1 and 4% (Table 2.3).

Subsequent to CEPESAF, a further prospective study was undertaken with 39 Spanish veterinary clinics and recorded data from 2012 anesthetics. Anesthetic death was defined as perioperative death within 24 h of the procedure end and a risk of death of 1.29% overall was reported, with risks in healthy dogs and cats of 0.33% and in sick animals 4.06% [11].

In summary, recent estimates of anesthetic-related death risks in small animal practice appeared to be of the order of 0.1–0.3%, although in some circumstances this may be higher, with the risk in healthy dogs and cats being approximately 0.05–0.30% and in sick dogs and cats 1–4% [3,4,11,12,49,56,76]. Cats appeared to be at greater risk of death than dogs in some work [3,49], and rabbits and other companion animal species appeared to be at even higher risk where studied [7]. In referral institutions, mortality ranged from 0.30 to 0.60% in dogs and cats [5,6,10,49,51].

Table 2.3 Anesthetic- and sedation-related risk of death in small animals in CEPESAF [7].

Species	No. of Anesthetic- and Sedation-related Deaths	No. Anesthetized and Sedated	Risk of Anesthetic-related Death (%) (95% Confidence Interval, %)
Dog	163	98036	0.17 (0.14–0.19)
Cat	189	79178	0.24 (0.20–0.27)
Rabbit	114	8209	1.39 (1.14–1.64)
Guinea Pig	49	1288	3.80 (2.76–4.85)
Hamsters	9	246	3.66 (1.69–6.83)
Chinchilla	11	334	3.29 (1.38–5.21)
Rat	8	398	2.01 (0.87–3.92)

Source: [7]. Reproduced with permission of Wiley.

Table 2.4 Risk of anesthetic- and sedation-related death in healthy and sick dogs, cats, and rabbits in CEPESAF [7].

Species	Health Status ^a	No. of Deaths ^b	Estimated No. of Anesthetics and Sedations	Risk of Anesthetic-related death (%) (95% Confidence Interval, %)
Dog	Healthy(ASA 1–2)	49	90618	0.05 (0.04–0.07)
	Sick(ASA 3–5)	99	7418	1.33 (1.07–1.60)
Cat	Healthy(ASA 1–2)	81	72473	0.11 (0.09–0.14)
	Sick(ASA 3–5)	94	6705	1.40 (1.12–1.68)
Rabbit	Healthy(ASA 1–2)	56	7652	0.73 (0.54–0.93)
	Sick(ASA 3–5)	41	557	7.37 (5.20–9.54)

^aASA 1–2, no/mild preoperative disease; ASA 3–5, severe preoperative disease.

^bOnly deaths where detailed information was available were included here.

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Causes of anesthetic death

The physiologic cause of many anesthetic deaths may be multifactorial, although cardiovascular and respiratory complications represent the primary causes of many perioperative deaths reported. Other causes reported include gastrointestinal-, neurologic-, and hepatic- or renal-related deaths. Cardiac arrest has been reported to result from cardiac arrhythmias associated with increased circulating catecholamines, myocardial hypoxia, specific anesthetic agents, pre-existing pathology, specific procedures (e.g., vagal traction and enucleation), and myocardial depression due to relative anesthetic overdose [35,78]. Between 30 and 70% of deaths resulted from relative anesthetic overdose and myocardial depression, cardiac arrhythmias or circulatory failure, and hypovolemia in a number of studies [3–5,56,74]. Halothane, ether, and thiobarbiturate anesthesia were frequently associated with anesthetic overdose in earlier work [3,76]. Dogs more frequently had cardiovascular complications than cats in one study and high-risk patients were the most likely patients to die from circulatory failure, often when hypovolemic [3].

Respiratory complications represented the other main cause of anesthetic-related death. Respiratory complications were an underlying cause of death in 30–40% of dogs and about 40–50% of cats [3,4,74]. Problems related to endotracheal intubation and respiratory obstruction represented the majority of feline respiratory causes of death [3,4]. In dogs, complications with endotracheal intubation and respiratory failure were equally reported, although in brachycephalic dogs respiratory obstruction was the principal cause of respiratory complications [3,4,76].

In small animal anesthesia, causes other than respiratory and cardiovascular complications have infrequently been reported, although have included postoperative renal failure, iliac thrombosis in cats, aspiration of gastric contents, anaphylactic reactions, failure to regain consciousness, and unknown causes [3,4,56,76]. The last causes, often arising when patients were not being closely watched, represented approximately 5–20% of patients.

Timing of death

The timing of anesthetic deaths has varied, with more recent studies increasingly highlighting the postoperative period. Albrecht and Blakely [72] reported in an early study only one death during induction and one during recovery, with the remainder of the deaths occurring during maintenance of anesthesia. In contrast, work at Colorado State University in the 1950s reported that of 36 dog and cat deaths, 17% occurred during induction, 22% during maintenance, and interestingly the majority (61%) during recovery [73]. However, later work at Colorado (1979–1981) reported mostly intraoperative deaths [74] and work there in the 1990s reported that only approximately 25% of dogs and cats died during recovery, with the rest dying during anesthesia [51]. Other referral institutions reported differing high-risk periods; Hosgood and Scholl [5,10] documented that 9 of 14 (61%) deaths in dogs and 4 of 7 (57%) in cats occurred postoperatively, although the number of deaths recorded was small and included all causes of death.

In the primary practice setting, only the larger studies quantified the timing of fatalities. Clarke and Hall [3] reported deaths occurring principally during anesthesia. In dogs, 22% died on induction of anesthesia, 55% during maintenance, and 18% in recovery, whereas in cats, 30% died during induction, 39% during anesthesia, and 31% during recovery. Similarly, in the study in Ontario, Canada [4], most dogs and cats died during anesthesia (6/9 dogs and 7/8 cats) and only 33% and 13% of dogs and cats, respectively, died postoperatively (3/9 dogs and 1/8 cats). More recently, CEPESAF

Table 2.5 Timing of death in dogs, cats, and rabbits in CEPSAF [7].

Timing of Death	Dogs	Cats	Rabbits
After premedication	1 (1%)	2 (1%)	0
Induction of anesthesia	9 (6%)	14 (8%)	6 (6%)
Maintenance of anesthesia	68 (46%)	53 (30%)	29 (30%)
Postoperative death ^a :	70 (47%)	106 (61%)	62 (64%)
0–3 h PO	31	66	26
3–6 h PO	11	9	7
6–12 h PO	12	7	13
12–24 h PO	13	12	9
24–48 h PO	3	10	3
Unknown time	0	2	4
Total ^b	148 (100%)	175 (100%)	97 (100%)

^aPostoperative (PO) deaths were additionally categorized by time after anesthesia.

^bOnly deaths where detailed information was available were included here.

Source: [7]. Reproduced with permission of Wiley.

highlighted the postoperative period as the most common time for dogs, cats, and rabbits to die [49]. Over 60% of cats and rabbits and nearly 50% of dogs died during this time period (see Table 2.5). Notably, most of these postoperative deaths occurred within 3 h of termination of the procedure, suggesting that increased vigilance, particularly in the early postoperative period, could reduce the risk of death. Subsequent to this study, work in Spain further highlighted the postoperative period, with over 75% of dogs dying in this multiclinic practice study after anesthesia [11]. Hence, increasingly, the postoperative period represented a high-risk time and close monitoring and management until full recovery is observed are to be recommended.

Risk factors for anesthetic death

Early institution-based studies suggested contributory factors without providing in-depth analysis of risk factors [72,73]. The use of specific drugs was associated with higher mortality in dogs and cats, and trauma patients, neutering procedures, certain breeds including brachycephalic, terrier, and spaniel breeds in dogs were frequently represented amongst the fatalities [72–74]. Old age and poor health status were associated with increased odds of mortality in dogs and poor health status only in cats in a subsequent referral-based study [5,10]. Work at the Royal Veterinary College also reported poor health status as increasing odds and additionally premedication with acepromazine being associated with reduced odds of death in dogs [6]. Although they identified important risk factors, all of these studies were single-center referral studies with small sample sizes and limited abilities to detect more than a small number of major risk factors.

Early practice-based work was also limited in its ability to evaluate risk factors. Dodman [75] identified a trend to reduced risk with thiopental (thiopentone)/halothane anesthesia relative to other drugs in feline anesthetic practice. In a later study, Dodman and Lamb [76] identified high risk with xylazine administration and in brachycephalic breeds, although in both of these studies quantification of risk factors was limited. Clarke and Hall identified a number of risk factors for anesthetic death in healthy dogs and cats [3]. Higher risks were seen with administration of the α_2 -adrenergic receptor agonist xylazine and reduced risk with premedication with atropine or acepromazine. In cats, endotracheal intubation, induction of anesthesia with a volatile agent, thiopental, methohexital (methohexitone), ketamine, halothane, ether, and nitrous oxide use were also associated with higher risks of death and administration of alphadolone/alphaxalone (Saffan[®]) with lower risks, although

statistical comparisons were not made. In dogs, Pekingese were the most commonly reported breed to die. Administration of xylazine was associated with higher risk of death whereas halothane and thiopental use was associated with lower death risks. The Ontario study identified similar risk factors with xylazine administration and sick patients (ASA 3–5) being at increased odds of cardiac arrest in dogs, whereas in cats, sick patients (ASA 3–5) were at greater risk while the presence of a technician monitoring anesthesia reduced the risk [4]. A study at a single center in France also highlighted increased risk with poor health status [12], and this was supported by a multicenter study in Spain [11].

More recently in CEPSAF, within larger study populations a number of risk factors were evaluated within multivariable logistic regression models for cats and dogs [9,79]. In cats, increasing ASA grade, procedural urgency, major versus minor intended procedures, increasing age, extremes of weight, endotracheal intubation, and the use of fluid therapy were associated with increased odds of anesthetic and sedation-related death (Table 2.6) [79]. Pulse and pulse oximetry monitoring were associated with a reduction in odds. In dogs, poorer health status (based on ASA grade), greater procedural urgency, major versus minor intended procedures, old age, and low weight were associated with anesthetic-related death. Additionally, increasing duration of the procedure and the anesthetic induction and maintenance combination used were associated with increased odds of anesthetic-related death. Maintenance with halothane after induction of anesthesia with an injectable anesthetic agent and dogs undergoing total inhalational anesthesia were both associated with an approximately sixfold increase in odds compared with isoflurane maintenance after induction of anesthesia with an injectable anesthetic agent [9].

The association between patient health status (ASA grade) and anesthetic-related death was repeatedly documented in many of the studies described and has been discussed above [3–6,11,12,50,79]. Pre-existing pathology may reduce the therapeutic index of administered anesthetics, predispose to cardiopulmonary depression, and depress other physiologic functions significantly. Additionally, in CEPSAF, procedural urgency was associated with increased odds of death [9,79]. Hence greater attention to preoperative assessment and stabilization of the patient prior to the procedure could substantially reduce fatalities.

Increased risk with increasing age, independent of patient physical status (ASA grade), was also identified as an important risk factor; however, only some of the more recent work in small animals has reported this [5,9,79]. Old patients may be more susceptible to the depressant effects of anesthetics, to hypothermia via impaired thermoregulatory mechanisms, and to prolonged recovery due to tendencies to reduced metabolic function and hypothermia [80–82].

Increased odds of death reported for small dogs and cats in CEPSAF [9,79] were consistent with work in pediatric anesthesia [83]. Smaller patients could be more prone to drug overdose, to hypothermia, and to perioperative management difficulties (e.g., intravenous catheter placement, endotracheal intubation). Increased risk with increasing weight seen in cats likely reflected, at least in part, risks associated with obesity [79]. Interestingly, although there was a tendency to a breed association in dogs in CEPSAF, after adjusting for weight this association dropped out. This suggested that a major aspect of the risk associated with breed could be related to animal size [9]. Nonetheless, other work has reported increased complications with brachycephalics and terrier breeds [3,4,73], and caution with the anesthesia of these breeds may be advisable.

Table 2.6 Multivariable model of risk factors for anesthetic- and sedation-related death in cats in CEPSAF [8].

Risk Factor	Categories	Odds Ratio ^a	95% Confidence Interval (%)	P value
Health status (ASA grade ^b)	ASA 4–5 vs ASA 3 vs ASA 1–2 (trend ^c)	3.2	2.0–5.0	<0.001
Urgency of procedure	Emergency vs urgent vs scheduled (trend ^c)	1.6	1.0–2.5	0.050
Intended procedure	Minor procedure	1		
	Major procedure	2.7	1.4–5.4	0.005
Age	0–0.5 years	0.4	0.1–2.4	0.058
	0.5–5 years	1		
	5–12 years	1.7	0.9–3.0	
	12 years–max.	2.1	1.1–3.9	
Weight	0–2 kg	15.7	2.9–83.6	
	2–6 kg	1		
	6 kg–max.	2.8	1.1–7.4	
	Unknown	1.1	0.2–5.5	0.002
Endotracheal (ET) intubation	No ET tube	1		
	ET tube	1.9	1.0–3.7	0.042
Pulse and pulse oximeter used	None	1		
	Pulse assessed only	0.3	0.2–0.6	
	Pulse oximeter used only	0.2	0.1–0.5	
	Pulse and pulse oximeter	0.2	0.1–0.4	<0.001
Perioperative intravenous (IV) fluids	No fluids given	1		
	IV catheter used only	0.7	0.2–2.5	
	IV fluids given	3.9	2.2–7.1	<0.001

^aOdds ratios greater than 1.0 indicate increased odds whereas odds ratios less than 1.0 indicate reduced odds of anesthetic-related death.

^bASA 1–2, healthy/moderate disease only; ASA 3, severe disease, limiting activity; ASA 4–5, life-threatening disease.

^cTrend represents the odds ratio for a one-category increase in the risk factor.

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Increasing risk for patients presenting for major procedures, as documented in CEPSAF [79], was consistent with work in equine anesthesia [14,53]. More complex and invasive procedures were likely to impose greater stress on patient physiology, and when assessing patient risk prior to anesthesia, assessment of the procedure's complexity should be considered. Increasing duration, in addition to type of procedure, was associated with increased risk in dogs in CEPSAF [9]. Longer procedures could expose the patient to extended periods of physiologic compromise, increased hypothermia and fluid loss and could be expected to predispose to greater risk [35]. The previously unreported association of increased risk of death associated with fluid therapy administration in cats in CEPSAF was surprising [79]. Although this may have reflected in part residual confounding, a component of the increased odds may have been related to excessive administration of fluids and fluid overload. Careful fluid administration and monitoring are recommended in cats, although further work is needed to confirm this observation.

The reduction in odds of anesthetic-related death with pulse and pulse oximetry monitoring in cats in CEPSAF has not been reported previously in small animals [79]. Theoretical analyses in human anesthesia support these findings and have suggested that pulse oximetry would have detected 40–82% of reported perioperative incidents, and when combined with capnography 88–93% [84–86]. These associations suggest that some form of assessment of cardiovascular function (pulse quality and rate) and respiratory function (oxygen saturation and end-tidal CO₂) may be important in minimizing mortality.

The role of specific anesthetic drugs in anesthetic death has been evaluated in a number of small animal studies. The premedication administered was a risk factor in a number of studies in dogs and cats [3,4,6,53]. Early work had identified acepromazine as being associated with reduced odds of death [3,6] and major morbid complications [4], compared with no premedication, whereas the α_2 -adrenergic receptor agonist xylazine was associated with increased odds of death [3,4]. In CEPSAF, although there were trends to reduced odds with the administration of acepromazine, after adjustment for major confounders this was not a major factor

in dogs or cats. Further, when evaluating premedication with the α_2 -adrenergic receptor agonist medetomidine, no increased odds of death was detected [9,79]. Xylazine has been found to reduce the threshold to catecholamine-induced arrhythmias under halothane anesthesia [87,88], whereas medetomidine did not [89]. This difference, combined with a greater awareness of the physiologic effects and a better understanding of the optimal method of administration of α_2 -adrenergic receptor agonists, may be the basis of a lack of increased risk with medetomidine compared with acepromazine observed in CEPSAF.

The specific induction agent used did not appear important in CEPSAF, in contrast to the tendency for increased risk with the use of thiopental and ketamine in cats and lower risk with alphadolone/alphaxalone (Saffan®) in cats and thiopental in dogs in the last United Kingdom study [3,9,79]. The lack of a consistent difference in risks with different induction agents likely reflects that the effect of induction agent was small. The maintenance agent used, however, was relevant to dogs in CEPSAF, and isoflurane appeared to be associated with reduced odds compared with halothane after induction of anesthesia with an injectable anesthetic agent. This is supported by clinical studies indicating that although isoflurane induces greater respiratory depression and vasodilation than halothane, it causes less direct myocardial depression and sensitizes the heart less to catecholamine-induced arrhythmias, and on balance would appear to cause less overall cardiovascular depression [90–99].

In summary, only the more recent studies have critically evaluated risk factors for death [3–6,9–12,50,79]. Commonly reported risk factors for death include poor health status, old age, poor monitoring, endotracheal intubation in cats, and possible breed associations in dogs [3–6,9,10,79]. Additionally, CEPSAF identified a number of previously unreported risk factors, including the use of pulse oximetry and pulse monitoring reducing odds and fluid therapy increasing odds of death in cats and isoflurane maintenance being associated with reduced odds compared with halothane after an induction of anesthesia with an injectable anesthetic agent in dogs [9,79]. Awareness of these risk factors can aid veterinarians in identifying