

General Anesthesia

Fatal and non fatal cardiac arrests related to anesthesia

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Purpose: The aim of this study was to assess the incidence and causes of cardiac arrests related to anesthesia.

Methods: All patients undergoing anesthesia over a six year period were included in a prospective study. The cardiac arrests encountered during anesthesia and the first twelve postoperative hours in the PACU or ICU were analysed. For each arrest, partially or totally related to anesthesia, the sequence of events leading to the accident was evaluated.

Results: Eleven cardiac arrests related to anesthesia were identified among the 101,769 anesthetic procedures (frequency : 1.1/10,000 [0.44-1.72]). Mortality related to anesthesia was 0.6/10,000 [0.12-1.06]. Age over 84 yr and an ASA physical status > 2 were found to be risk factors of cardiac arrest related to anesthesia. The main causes of anesthesia related cardiac arrest were anesthetic overdose (four cases), hypovolemia (two cases) and hypoxemia due to difficult tracheal intubation (two cases). No cardiac arrests due to alveolar hypoventilation were noted during the postoperative periods in either PACU or ICU. At least one human error was noted in ten of the eleven cardiac arrests cases, due to poor preoperative evaluation in seven. All cardiac arrests totally related to anesthesia were classified as avoidable.

Conclusion: Efforts must be directed towards improving preoperative patient evaluation. Anesthetic induction doses should be titrated in all ASA 3 and 4 patients. The prediction of difficult tracheal intubation, and if required, the use of awake tracheal intubation techniques, should remain a priority when performing general anesthesia.

Objectif : Le but de cette étude était d'évaluer la fréquence et les causes des arrêts cardiaques liés à l'anesthésie (ACA).

Méthode : Toutes les anesthésies effectuées pendant six ans dans un département d'anesthésie ont été relevées de manière prospective. Les arrêts cardiaques notés en peropératoire et dans les 12 premières heures postopératoires en salle de réveil ou en réanimation ont été

analysés. Pour chaque arrêt cardiaque lié partiellement ou totalement à l'anesthésie, l'étude des causes de l'accident était réalisée.

Résultats : Onze ACA ont été relevés sur 101769 anesthésies effectuées (fréquence de 1.1/10000 [0.44-1.72]). La mortalité liée à l'anesthésie était de 0.6/10000 [0.12-1.06]. Un âge de plus de 84 ans et un score ASA supérieur à 2 étaient des facteurs de risque de survenue d'ACA. Les principales causes d'ACA étaient le surdosage anesthésique (quatre cas), l'hypovolémie (deux cas) et l'hypoxie par difficulté d'intubation trachéale (deux cas). Aucun ACA hypoxique postopératoire n'était relevé en salle de réveil ou en réanimation. Dans dix des onze ACA au moins, une erreur humaine était relevée, le plus souvent (sept cas) il s'agissait d'une mauvaise évaluation préopératoire. Tous les arrêts cardiaques totalement liés à l'anesthésie étaient classés évitables.

Conclusion : Une meilleure évaluation préopératoire semble primordiale. Chez les patients âgés et/ou avec un score ASA supérieur à 2, un titrage de la dose d'induction est indispensable. La prédiction d'une intubation difficile et, si nécessaire, l'utilisation des techniques d'intubation trachéale vigiles, doivent rester une priorité au cours d'une anesthésie générale.

THE causes of anesthesia related mortality have been examined in many epidemiological studies, allowing the proposal of preventive measures. Since the most recent publications,¹⁻⁷ anesthetic practice has evolved, taking these proposals under consideration, specific to each of the operative periods.^{8,9} The INSERM study revealed a high incidence of early postoperative hypoxemic cardiac arrest.² In consequence, our institution has adopted systematic postoperative supervision in a postanesthesia care unit (PACU), and the use of pulse oximetry and capnography has become widespread. Since our last epidemiological publication,⁵ we have regularly examined

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all anesthesia-related cardiac arrests, allowing follow-up of their evolution. The purpose of this study was to determine the incidence and to analyse the causes of anesthesia-related cardiac arrest, in order to discuss the need of new preventive measures for anesthetic security.

Patients and methods

From January 1, 1989 to December 31, 1995, all patients with an ASA 1 to ASA 4 physical status and undergoing anesthesia were included in this prospective study: ASA 5 patients were excluded.

Anesthesia practice

All patients were examined by an anesthesiologist prior to anesthesia. Basic safety monitoring included: continuous electrocardiogram display, automatic non invasive blood pressure, and pulse oximetry. When regional anesthesia was associated with sedation, or general anesthesia was performed, capnography, oxygen concentration, and delivered anesthetic vapour concentration were measured. Since 1992, laryngeal mask airway devices (LMA) were progressively used in our institution. Postoperative supervision was systematically performed in either a PACU or intensive care unit (ICU). Obligatory postoperative monitoring included pulse oximetry. An anesthesiologist's authorisation was required for all releases from the PACU or ICU.

Data collection

An information form was edited on which details of the anesthesia were reported by the anesthesiologist: patient identification, age, ASA physical status, elective or emergency procedure, anesthetic techniques, surgical procedures, complications encountered during anesthesia and the first twelve postoperative hours in the PACU or ICU. Surgery was classified as an emergency procedure when not scheduled, and either performed within the first 24 hr of admission, or later if urgently indicated. When regional and general anesthesia were combined, only regional anesthesia was retained. The forms were regularly checked by a senior anesthesiologist, verifying the quality and completeness of the information. In order to minimize the risk of under-recording cardiac arrests, this information was cross-checked with regular medical staff interviews, ICU admission records, and hospital administrative files.

Analysis of cardiac arrests

For each reported cardiac arrest, the patient's medical record and, when applicable, the autopsy report, were analyzed by two of the authors. The classification of the cardiac arrests used in the INSERM² and our previous⁵ studies was applied. When requiring external cardiac

massage or electric defibrillation, asystole, ventricular fibrillation and electro-mechanical dissociation were considered as cardiac arrests. Recovery was defined as an alive and non-comatose patient 24 hr after the arrest. The cardiac arrest was assigned to one of three groups: (1) totally related to anesthesia when anesthesia was the only or the major contributive factor, (2) partially related to anesthesia when patient condition or surgical procedure were major contributive factors, but anesthesia represented an additional factor, or (3) unrelated to anesthesia. The causes of the cardiac arrests were classified according to the primary responsible mechanism.^{2,5} Cooper's classification¹⁰ was then applied to qualify and quantify the errors associated with each procedure. Finally the arrest was classified as avoidable or not.

Statistical analysis

Event incidences are expressed for 10,000 anesthetics (0/000) with their 95% confidence intervals in brackets. Univariate analysis was used to test risk factors for cardiac arrest: ASA 1 and 2 vs ASA 3 and 4, age < 85 vs age > 84 yr, emergency vs elective. Statistical significance was retained when $P < 0.05$.

Results

Within the six years of the study, 101,769 anesthetics were performed: orthopedic ($n = 45,852$), pediatric ($n = 19,851$), urological ($n = 16,325$), otorhinolaryngological ($n = 11,985$) and maxillofacial surgery ($n = 7,756$). During this period, 24 cardiac arrests were identified, including 13 unrelated to anesthesia.

Of the 11 anesthesia related cardiac arrests, 1.1/10,000 [0.44 - 1.72], three were considered totally, and eight partially related to anesthesia. Risk factors for anesthesia related cardiac arrest were age > 84 yr (P

TABLE I Incidence of cardiac arrests and deaths related to anesthesia according to age

Age group (yr)	Anesthetics		Cardiac arrests		Deaths	
	n	%	n	incidence (p 1000)	n	incidence (p 1000)
< 4	11959	(11.7)	0		0	
5-14	11873	(11.7)	1	(0.08)	1	(0.08)
15-34	26979	(26.5)	0		0	
35-54	21971	(21.6)	2	(0.09)	0	
55-74	21443	(21.0)	4	(0.19)	1	(0.05)
75-84	5456	(5.4)	1	(0.18)	1	(0.18)
> 84	2088	(2.1)	3	(1.44)*	3	(1.44)*

*Comparison between patients > 84 yr old ($n = 2088$, incidence of arrests or deaths 1.4/1000 with a 95% confidence interval 0-3.06) vs all patients < 85 yr old ($n = 99,681$, incidence of arrests 0.08/1000 with a 95% confidence interval 0.02-0.14 and incidence of deaths 0.03/1000 with a 95% confidence interval 0-0.06) $P < 0.05$.

TABLE II Incidence of cardiac arrests and deaths related to anesthesia according to ASA physical status and surgical conditions

	Anesthetics		Cardiac arrests		Deaths	
	<i>n</i>	%	<i>n</i>	incidence (<i>p</i> 1000)	<i>n</i>	incidence (<i>p</i> 1000)
ASA 1	63184	(62.1)	1	(0.02)	0	
ASA 2	28375	(27.9)	2	(0.07)	1	(0.03)
ASA 3	9171	(9.0)	6	(0.66)*	3	(0.33)*
ASA 4	1039	(1.0)	2	(1.92)*	2	(1.92)*
Elective	80093	(78.7)	9	(0.11)	5	(0.06)
Emergency	21676	(21.3)	2	(0.09)	1	(0.05)

*Comparison between patients ASA 3 and 4 ($n = 10210$, incidence of arrests 0.78/1000 with a 95% confidence interval 0.24-1.33 and incidence of deaths 0.49/1000 with a 95% confidence interval 0.06-0.92) vs ASA 1 and 2 ($n = 91559$, incidence of arrests 0.03/1000 with a 95% confidence interval 0-0.07 and incidence of deaths 0.01/1000 with a 95% confidence interval 0-0.3) $P < 0.05$.

TABLE III Incidence of cardiac arrests and deaths related to anesthesia according to anesthetic technique

Anesthetic technique	Anesthetics		Cardiac arrests		Deaths	
	<i>n</i>	%	<i>n</i>	incidence	<i>n</i>	incidence
General anesthesia	71826	(70.6)	6	(0.08) (0.02-0.15)	2	(0.03) (0-0.07)
Regional anesthesia	29943	(29.4)	5	(0.17) (0.02-0.3)	4	(0.13) (0-0.26)
Epidural	4145		0		0	
Spinal	7656		5	(0.65)	4	(0.52)
Caudal	2081		0		0	
IVRA	3308		0		0	
Plexus blocks	9222		0		0	
Nerve blocks	3531		0		0	

IVRA: intravenous regional anesthesia

Values of cardiac arrests and deaths are the number, the incidence per 1000 and the 95% confidence interval.

Statistical analysis was not performed as the distribution of the anesthetic technique differed in function of the patients age and ASA physical status.

< 0.01), ASA 3 and 4 ($P < 0.001$). Emergency surgical conditions were not retained as a risk factor (Tables I, II). Five patients recovered following cardiac arrest. Anesthesia related mortality was 0.6/10,000 [0.12-1.06]. Cardiac arrests related to regional anesthesia were noted only during spinal anesthesia (Table III).

The causes of cardiac arrest were related to anesthetic overdose ($n = 4$) primarily encountered during spinal anesthesia ($n = 3$), hypovolemia ($n = 2$), hypoxemia due to airway management difficulties ($n = 2$), and pacemaker malfunction ($n = 1$) (Table IV, V). In two cases, (patient #7 and #11), the exact cause of the

cardiac arrest could not be determined. However, the arrest was retained as partially anesthesia related as an anesthetic overdose was identified in patient #7 and patient #11 was hypovolemic.

At least one human error was encountered in 10 of the 11 arrests. Inadequate preoperative risk estimation was noted in 7/11 cardiac arrests: patient diseases were not controlled in four cases, intraoperative airway management difficulties were underestimated in two, and a probable thrombophlebitis was ignored in a bedridden obese patient. Intraoperative errors or misjudgments were noted in 10/11 cardiac arrests: inadequate fluid replacement ($n = 7$), anesthetic overdosage ($n = 4$), continuation of the surgical procedure despite an unstable hemodynamic state ($n = 3$), error in airway management technique choice ($n = 2$), insertion of methyl-metacrylate cement in a hypovolemic patient ($n = 2$), mobilization of a hypovolemic patient ($n = 1$), inadequate prevention of hypothermia ($n = 1$). The association of inadequate preoperative risk estimation and intraoperative errors were noted in 7/11 cardiac arrests. All cardiac arrests totally related to anesthesia were classified as avoidable.

Discussion

Over the six years of the study, the incidence of anesthesia related cardiac arrest was 1.1/10,000 [0.44-1.72], and anesthesia related mortality was 0.6/10,000 [0.12-1.06]. This incidence was particularly high in ASA 3 and 4 patients: 7.8/10,000 cardiac arrest and 4.9/10,000 deaths related to anesthesia. The three most frequent causes of cardiac arrest were overdose, hypovolemia and hypoxemia. Human error was noted in 91% of the arrests. This study has pointed out that anesthesia-related cardiac arrests are predominantly multifactorial, associating inadequate preoperative risk estimation, intraoperative errors or misjudgments, and poor preoperative patient condition.

Affirming the exhaustive inclusion of all data in this type of epidemiological study is impossible. When considering the denominator, the number of anesthetics recorded was regularly compared to the number of surgical procedures registered in the administrative files. A possible under-reporting in the number of anesthesia related cardiac arrests was reduced by limiting the study to only one department of anesthesia. Regular contacts with all staff, as well as checking the ICU admission registers identified two anesthesia related cardiac arrests not retained in the computer files. Moreover, as recovery was defined as a live non-comatose patient 24 hr after the arrest, we ignored later outcomes. Finally, cardiac arrests which occurred just after departure from the PACU were not retained.

TABLE IV Description of the cardiac arrest related to anesthesia

#	Age (yr)	Sex	ASA status	Patient's medical history	Surgical procedure	Anesthetic technique	Description	Outcome
1	93	F	3	Ischemic heart disease Hypertension	Hip arthroplasty for hip fracture	general	Severe post-induction hypotension	Cardiac failure and death 10 hr after arrival in the PACU
2	91	F	4	Ischemic heart disease Chronic renal failure	Hip arthroplasty for hip fracture	spinal	Severe post-induction hypotension Sensory level at T2	Cardiac failure and death at the end of the procedure
3	100	M	4	COPD Chronic heart failure Chronic renal failure	Hip arthroplasty for hip fracture	spinal	Severe post-induction hypotension Sensory level at T4	Cardiac failure and death 4 hours after arrival in the PACU
4	62	F	3	Restrictive lung disease Ankylosing spondylitis	Hip arthroplasty for hip fracture	general	Cardiac arrest after the insertion of the cemented femoral component	Recovered
5	60	M	3	Paraplegic	Pedicle graft of latissimus dorsi muscle	general	Cardiac arrest at the end of the procedure while transferring the patient from the operating table	Recovered
6	35	M	1 E		Foot wound	spinal	Bradycardia and asystole just after the tourniquet release, one hour after induction Sensory level at T ₄	Recovered
7	56	F	3	Obesity COPD Diabetes mellitus	Exploration for recurrent knee dislocation	spinal	Sudden cardiac arrest during mobilisation of the knee, 10 min after induction sensory level at T6, five minutes after induction	Death
8	58	F	3	COPD Alcoholism	Laryngectomy	general	Failure to intubate and ventilate after induction	Recovered
9	14	F	2	Nephroblastoma with Mediastinal adenopathy	Excision of a pulmonary metastasis	general	Failure to intubate and ventilate after induction	Death
10	52	M	2	Atrioventricular block. Pacemaker verified prior to surgery	Acromioplasty	general	Asystolic cardiac arrest during induction without allergic reaction	Recovered
11	77	F	3	Poorly regulated arterial hypertension Diabetes mellitus Dehydration	Hip arthroplasty for hip fracture	spinal	Cardiac arrest five minutes after insertion of the cemented femoral component	Death

It is difficult to compare the incidence of anesthesia related cardiac arrests and deaths reported in this work with those of previous studies, as the methods differ greatly among studies. Some were based on the voluntary declaration of incidents,^{3,7} others on case series,^{1,2,4-6,11} of which only two were prospective studies.^{2,12} Some include only critical incidents occurring during the intraoperative period,^{1,4} while others include only those totally related to anesthesia.^{3,11} The patient populations differ considerably among studies. Consequently, it seems hazardous to compare the incidence of anesthesia related cardiac arrests and anesthesia related mortality among studies.¹³ In contrast, the analysis of the causes of these arrests seems instructive.

Hypoxemia is classically considered the most frequent cause of anesthesia-related cardiac arrest, estimated to be between 0.4 and 1.1/10,000 in the intraoperative period,^{1,2,4,5} and 1.1/10,000 in the postoperative period when only 40% of patients were supervised in a PACU or ICU.² In our study, hypoxemia was retained as the cause in only two anesthesia related cardiac arrest (0.2/10,000). Both cases involved difficult tracheal intubation, and were considered to be a result of poor preoperative assessment, leading to the use of inappropriate anesthetic induction techniques. In contrast with the literature, the two most common causes of hypoxemic cardiac arrests, inadequate ventilation and esophageal intuba-

TABLE V Analysis of the cardiac arrest related to anesthesia

#	Cause of cardiac arrest	Type of human error		Analysis
		Preoperative	Intraoperative	
1	Anesthetic overdose	<ul style="list-style-type: none"> Inadequate preoperative assessment Inadequate preparation of anesthesia 	<ul style="list-style-type: none"> Anesthetic overdose Operation performed despite unstable hemodynamic state Inadequate fluid replacement 	Partially related to anesthesia
2	Anesthetic overdose	<ul style="list-style-type: none"> Inadequate preoperative assessment Inadequate preparation of anesthesia 	<ul style="list-style-type: none"> Anesthetic overdose Operation performed despite instable hemodynamic state Inadequate fluid replacement 	Partially related to anesthesia
3	Anesthetic overdose	<ul style="list-style-type: none"> Inadequate preoperative assessment Inadequate preparation of anesthesia 	<ul style="list-style-type: none"> Anesthetic overdose Operation performed despite instable hemodynamic state Inadequate fluid replacement 	Partially related to anesthesia
4	Hypovolemia		<ul style="list-style-type: none"> Inadequate fluid replacement Insertion of methyl-metacrylate cement in an hypovolemic patient 	Partially related to anesthesia
5	Hypovolemia		<ul style="list-style-type: none"> Inadequate fluid replacement Inadequate prevention of hypothermia Mobilisation of an hypovolemic patient 	<ul style="list-style-type: none"> Totally related to anesthesia Avoidable
6	Anesthetic overdose and hypovolemia		<ul style="list-style-type: none"> Inadequate fluid replacement Anesthetic overdose 	Partially related to anesthesia
7	Unassessable as a pulmonary embolism could not be eliminated by a post-mortem examination	<ul style="list-style-type: none"> Inadequate preoperative assessment (no attempt was made to screen this obese bedridden patient for thrombophlebitis) 	<ul style="list-style-type: none"> Anesthetic overdose 	Partially related to anesthesia
8	Hypoxemia	<ul style="list-style-type: none"> Inadequate preoperative assessment Inadequate preparation for anesthesia 	<ul style="list-style-type: none"> Wrong choice of airway management technique 	<ul style="list-style-type: none"> Totally related to anesthesia Avoidable
9	Hypoxemia	<ul style="list-style-type: none"> Inadequate preoperative assessment Inadequate preparation for anesthesia 	<ul style="list-style-type: none"> Wrong choice of airway management technique 	<ul style="list-style-type: none"> Totally related to anesthesia Avoidable
10	Pacemaker malfunction due to electrical interference			Partially related to anesthesia
11	Unassessable as the anesthetic record was incomplete (sensory level?)	<ul style="list-style-type: none"> Inadequate preoperative assessment Inadequate preparation for anesthesia 	Inadequate fluid replacement	Partially related to anesthesia

tion,^{1,4,14} were not observed in our study. Furthermore, no hypoxemic arrests were noted in the postoperative period in either the PACU or ICU. It is tempting to explain this result by the systematic use of pulse oximetry and capnography, and the systematic supervision in a PACU or ICU. The ASA closed claim study reported that 57% of anesthesia related deaths were avoidable by the use of pulse oximetry and capnography.¹⁵ With the use of such monitoring in more than one million anesthetics, the anesthesia-related arrests decreased from 0.13/10,000 to 0.04/10,000 anesthetics.¹⁶ To reach statistical significance, this study would have required the inclusion of

more than seven million anesthetics.¹⁷ Furthermore this study included only ASA 1 and 2 patients, evaluating only the intraoperative period. As such, further studies are necessary to confirm the low incidence of hypoxemic cardiac arrest noted in our study using systematic pulse oximetry, capnography, and PACU or ICU postoperative supervision. The role of LMA in anesthetic safety is difficult to assess. In this study, the two hypoxemic arrests secondary to a "cannot ventilate, cannot intubate" situation were due to a laryngeal tumour in one case, and tracheal compression by a mediastinal mass in the other. The LMA was not used in either. Though pathology below the vocal

cords is considered to be a relative contraindication to the use of LMA,¹⁸ some anesthesiologists do not retain this notion.¹⁹ With the generalisation of the intubating LMA use, further studies are necessary to analyse these hypoxemic cardiac arrests.

In the present study, anesthetic overdose was the primary cause of anesthesia-related cardiac arrest and death. Arrests due to spinal anesthetic overdoses are particularly frequent, 3/7,656 spinal anesthesia, occurring in elderly patients in two of the cases. Spinal anesthesia overdosage is a well known cause of cardiac arrest in the elderly,^{4,5,13,20} with doses as low as 5 mg of either isobaric or hyperbaric bupivacaine, reaching sensory levels of T4²¹ / T2.²² Accordingly, single shot spinal anesthesia should be avoided in the elderly, favouring techniques which allow for dose titration, such as continuous spinal anesthesia.^{21,22} In contrast, no cardiac arrests were noted during other regional anesthesia techniques, including those with a risk of local anesthetic toxicity. Similar results were reported in two recent publications examining 25,697²³ and 51,691²⁰ epidural or nerve block procedures.

Human error has long been identified as a major factor leading to anesthesia-related cardiac arrest.^{1,3,4,7,12} In this study, anesthesia-related cardiac arrest resulted from the association of numerous common human errors, previously called the chain of accident evolution.²⁴ In accordance with an Australian study,⁷ poor preoperative preparation was the human error most often identified in this work. Human error has more consequences on patients with higher ASA scores as their ability to adapt to aggression is limited.^{10,12} As all identified errors did not lead to cardiac arrest, one can suppose that the incidence of errors is far greater than that noted in this work. Preventing human error is a complex task. In anesthesia, research based on models derived from aeronautics has started.^{25,26} Continued education of anesthesia practitioners is fundamental, however some studies demonstrate that it is poor practical application rather than a lack of knowledge that leads to critical incidents.²⁷ Training programs based on simulations of critical anesthetic scenarios have been proposed.^{28,29} However, the errors identified in this study were encountered in ordinary situations such as anesthesia in the elderly, in hypovolemic patients, and when a difficult intubation had been predicted; not exceptional situations. These findings do not minimize the need of regular training to meet the needs of exceptional situations, but rather underline the interest of regular epidemiological surveillance of the causes of the critical incidents.

In conclusion, this study highlights several simple means of improving anesthetic safety. Preoperative patient

evaluation must be thorough. Anesthetic induction doses should be titrated in all ASA 3 and 4 patients. Predicting difficult tracheal intubation followed, when necessary, by the use of awake intubation techniques, should remain a priority when performing general anesthesia.

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