



ROYAUME DU MAROC
UNIVERSITE MOHAMMED V DE
RABAT
FACULTE DE MEDECINE ET DE
PHARMACIE
RABAT



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SEVERE CARDIAC COMPLICATIONS IN PERIOPERATIVE NEUROSURGERY

THESIS

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BY

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Born on July 1st, 1994 in Rabat

FOR THE DEGREE OF
Doctor of Medicine

Key Words : Adverse Events; Perioperative Care; Cardiac complications;
Neurosurgery; Resuscitation

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Professor of Anesthesia and Critical Care

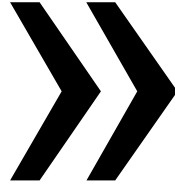
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Professor of Anatomy

**President &
Director**

Examiner

Examiner



قالوا سبحانك لا علم لنا إلا ما
علمتنا إنك أنت العليم الحكيم

سورة البقرة: الآية: 31

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1989 - 1997: Professeur Mohamed Tahar ALAOUI
1997 - 2003: Professeur Abdelmajid BELMAHI
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PROFESSEURS DE L'ENSEIGNEMENT SUPERIEUR :

Décembre 1984

Pr. MAAOUNI Abdelaziz
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Pr. SETTAF Abdellatif

Médecine Interne - [Clinique Royale](#)
Anesthésie -Réanimation
Pathologie Chirurgicale

Décembre 1989

Pr. ADNAOUI Mohamed
Pr. OUAZZANI Taïbi Mohamed Réda

Médecine Interne – [Doyen de la FMPR](#)
Neurologie

Janvier et Novembre 1990

Pr. KHARBACH Aïcha
Pr. TAZI Saoud Anas

Gynécologie -Obstétrique
Anesthésie Réanimation

Février Avril Juillet et Décembre 1991

Pr. AZZOUZI Abderrahim
Pr. BAYAHIA Rabéa
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Anesthésie Réanimation
Néphrologie
Chirurgie Générale
Pharmacie galénique
Ophtalmologie
Gynécologie Obstétrique Méd. [Chef Maternité des Orangers](#)
Pharmacologie
Histologie Embryologie
Pédiatrie
Pharmacologie- [Dir. du Centre National PV Rabat](#)
Chimie thérapeutique

Décembre 1992

Pr. AHALLAT Mohamed
Pr. BENSOUDA Adil
Pr. CHAHED OUAZZANI Laaziza
Pr. CHRAIBI Chafiq
Pr. EL OUAHABI Abdessamad
Pr. FELLAT Rokaya
Pr. JIDDANE Mohamed
Pr. ZOUHDI Mimoun

Chirurgie Générale [Doyen de FMPT](#)
Anesthésie Réanimation
Gastro-Entérologie
Gynécologie Obstétrique
Neurochirurgie
Cardiologie
Anatomie
Microbiologie

Mars 1994

Pr. BENJAFFAR Nouredine
Pr. BEN RAIS Nozha
Pr. CAOUI Malika
Pr. CHRAIBI Abdelmjid
Pr. EL AMRANI Sabah
Pr. ERROUGANI Abdelkader
Pr. ESSAKALI Malika
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Pr. IFRINE Lahssan
Pr. RHRAB Brahim
Pr. SENOUCI Karima

Radiothérapie
Biophysique
Biophysique
Endocrinologie et Maladies Métaboliques [Doyen de la FMPA](#)
Gynécologie Obstétrique
Chirurgie Générale – [Directeur du CHIS](#)
Immunologie
Chirurgie Pédiatrique
Chirurgie Générale
Gynécologie –Obstétrique
Dermatologie

**Enseignant militaire*

Mars 1994

Pr. ABBAR Mohamed*
Pr. BENTAHILA Abdelali
Pr. BERRADA Mohamed Saleh
Pr. CHERKAOUI Lalla Ouafae
Pr. LAKHDAR Amina
Pr. MOUANE Nezha

Urologie [Inspecteur du SSM](#)
Pédiatrie
Traumatologie – Orthopédie
Ophtalmologie
Gynécologie Obstétrique
Pédiatrie

Mars 1995

Pr. ABOUQUAL Redouane
Pr. AMRAOUI Mohamed
Pr. BAIDADA Abdelaziz
Pr. BARGACH Samir
Pr. EL MESNAOUI Abbes
Pr. ESSAKALI HOUSSYNI Leila
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Pr. OUAZZANI CHAHDI Bahia
Pr. SEFIANI Abdelaziz
Pr. ZEGGWAGH Amine Ali

Réanimation Médicale
Chirurgie Générale
Gynécologie Obstétrique
Gynécologie Obstétrique
Chirurgie Générale
Oto-Rhino-Laryngologie
Urologie
Ophtalmologie
Génétique
Réanimation Médicale

Décembre 1996

Pr. BELKACEM Rachid
Pr. BOULANOUAR Abdelkrim
Pr. EL ALAMI EL FARICHA EL Hassan
Pr. GAOUZI Ahmed
Pr. OUZEDDOUN Naima
Pr. ZBIR EL Mehdi*

Chirurgie Pédiatrie
Ophtalmologie
Chirurgie Générale
Pédiatrie
Néphrologie
Cardiologie [Directeur HMI Mohammed V](#)

Novembre 1997

Pr. ALAMI Mohamed Hassan
Pr. BIROUK Nazha
Pr. FELLAT Nadia
Pr. KADDOURI Nouredine
Pr. KOUTANI Abdellatif
Pr. LAHLOU Mohamed Khalid
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Gynécologie-Obstétrique
Neurologie
Cardiologie
Chirurgie Pédiatrique
Urologie
Chirurgie Générale
Pédiatrie
Psychiatrie [Directeur Hôp. Ar-razi Salé](#)
Gynécologie Obstétrique

Novembre 1998

Pr. BENOMAR ALI
Pr. BOUGTAB Abdesslam
Pr. ER RIHANI Hassan
Pr. BENKIRANE Majid*

Neurologie Doyen de la FMP Abulcassis
Chirurgie Générale
Oncologie Médicale
Hématologie

Janvier 2000

Pr. ABID Ahmed*
Pr. AIT OUAMAR Hassan
Pr. BENJELLOUN Dakhama Badr Sououd
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Pr. CHARIF CHEFCHAOUNI Al Montacer
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Pneumo-phtisiologie
Pédiatrie
Pédiatrie
Pneumo-phtisiologie
Chirurgie Générale
Chirurgie Générale
Pneumo-phtisiologie
Neurochirurgie
Anesthésie-Réanimation
Médecine Interne

**Enseignant militaire*

Novembre 2000

Pr. AIDI Saadia
Pr. AJANA Fatima Zohra
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Pr. EL KHADER Khalid
Pr. GHARBI Mohamed El Hassan
Pr. MDAGHRI ALAOUI Asmae

Neurologie
Gastro-Entérologie
Chirurgie Générale
Cardiologie
Anesthésie-Réanimation
Pédiatrie - [Directeur Hôp. Cheikh Zaid](#)
Urologie
Endocrinologie et Maladies Métaboliques
Pédiatrie

Décembre 2001

Pr. BALKHI Hicham*
Pr. BENABDELJILIL Maria
Pr. BENAMAR Loubna
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Anesthésie-Réanimation
Neurologie
Néphrologie
Pneumo-physiologie
Gastro-Entérologie
Cardiologie
Pédiatrie
Rhumatologie
Anatomie
Radiologie
Radiologie
Anesthésie-Réanimation
Neuro-Chirurgie
Chirurgie-[Pédiatrique Directeur Hôp. Des Enfants Rabat](#)
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Pédiatrie - [Directeur Hôp. Univ. International \(Cheikh Khalifa\)](#)
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Chirurgie Générale [Directeur Hôpital Ibn Sina](#)
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Traumatologie Orthopédie
Chirurgie Vasculaire Périphérique [V-D chargé Aff Acad. Est.](#)
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Décembre 2002

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Pr. BENZEKRI Laila
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Cardiologie
Gastro-Entérologie
Biochimie-Chimie
Endocrinologie et Maladies Métaboliques
Dermatologie
Gastro-Entérologie
Anatomie Pathologique
Chirurgie Générale
Pédiatrie
Chirurgie Pédiatrique
Gynécologie Obstétrique

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Ophthalmologie
Pédiatrie
Oto-Rhino-Laryngologie
Chirurgie Générale
Anesthésie Réanimation
Pédiatrie
Chirurgie Générale

Janvier 2004

Pr. ABDELLAH El Hassan
Pr. AMRANI Mariam
Pr. BENBOUZID Mohammed Anas
Pr. BENKIRANE Ahmed*
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Oto-Rhino-Laryngologie
Gastro-Entérologie
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Neurologie
Traumatologie Orthopédie
Anatomie Pathologique
Radiologie
Gynécologie Obstétrique
Pédiatrie
Chirurgie Générale
Pédiatrie
Traumatologie Orthopédie
Chirurgie Cardio-Vasculaire
Ophthalmologie
Pharmacie Clinique
Chirurgie Générale
Cardiologie

Janvier 2005

Pr. ABBASSI Abdellah
Pr. AL KANDRY Sif Eddine*
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Pr. AMAZOUZI Abdellah
Pr. BAHIRI Rachid
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Pr. HESSISSEN Leila
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Pr. SBIHI Souad
Pr. ZERAIDI Najia

Chirurgie Réparatrice et Plastique
Chirurgie Générale
Rhumatologie
Ophthalmologie
Rhumatologie [Directeur Hôp. Al Ayachi Salé](#)
Pédiatrie
Cardiologie
Biophysique
Cardiologie (mise en disponibilité)
Pédiatrie
Radiologie
Chirurgie Cardio-vasculaire
Parasitologie
Histo-Embryologie Cytogénétique
Gynécologie Obstétrique

Avril 2006

Pr. ACHEMLAL Lahsen*
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Pr. BENCHEIKH Razika
Pr. BOUHAFS Mohamed El Amine
Pr. BOULAHYA Abdellatif*
Pr. CHENGUETI ANSARI Anas
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Rhumatologie
Hématologie
O.R.L
Chirurgie - Pédiatrique
Chirurgie Cardio – Vasculaire. [Directeur Hôpital Ibn Sina Marr.](#)
Gynécologie Obstétrique
Cardiologie

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Cardiologie
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Médecine Interne
Microbiologie
Radiologie
Urologie
Pédiatrie
Psychiatrie
Chirurgie – Pédiatrique
Pharmacie Galénique
Parasitologie
Radiothérapie
Psychiatrie
Endocrinologie
Pneumo – Phtisiologie
Biochimie
Pneumo – Phtisiologie

Octobre 2007

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Réanimation médicale
Pneumo phtisiologie
Traumatologie orthopédie
Parasitologie
Anesthésie réanimation
Biochimie-chimie
Pharmacie clinique
Ophtalmologie
Pharmacie galénique
Chirurgie cardio-vasculaire
Chirurgie générale
Anesthésie réanimation
Psychiatrie
Chirurgie plastique et réparatrice
Radiothérapie
Oncologie médicale
Dermatologie
Radiothérapie
Microbiologie
Réanimation médicale
Pneumo phtisiologie
Hématologie biologique
Biochimie-chimie
Microbiologie
Microbiologie
Radiothérapie
Ophtalmologie
Chirurgie générale
Traumatologie-orthopédie
Parasitologie
Cardiologie

Mars 2009

Pr. ABOUZAHIR Ali *
Pr. AGADR Aomar *
Pr. AIT ALI Abdelmounaim *
Pr. AKHADDAR Ali *

Médecine interne
Pédiatrie
Chirurgie Générale
Neuro-chirurgie

**Enseignant militaire*

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Pr. MESKINI Toufik
Pr. MESSAOUDI Nezha *
Pr. MSSROURI Rahal
Pr. NASSAR Ittimade
Pr. OUKERRAJ Latifa
Pr. RHORFI Ismail Abderrahmani *

Octobre 2010

Pr. ALILOU Mustapha
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Pr. MOUJAHID Mountassir*
Pr. ZOUAIDIA Fouad

Decembre 2010

Pr. ZNATI Kaoutar

Mai 2012

Pr. AMRANI Abdelouahed
Pr. ABOUELALAA Khalil *
Pr. BENCHEBBA Driss *

Radiologie
Rhumatologie
Neuro-chirurgie [Directeur Hôp.des Spécialités](#)
Anesthésie Réanimation
Anatomie
Biochimie-chimie
Dermatologie
Chirurgie Générale
Traumatologie-orthopédie
Chirurgie Vasculaire Périphérique
Hématologie clinique
Chirurgie Générale
Microbiologie
Médecine interne
Gynécologie obstétrique
Rhumatologie
Gastro-entérologie
Pédiatrie
Pédiatrie
Chimie Thérapeutique
Chirurgie Cardio-vasculaire
Pédiatrie
Hématologie biologique
Chirurgie Générale
Radiologie
Cardiologie
Pneumo-Phtisiologie

Anesthésie réanimation
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Physiologie
Microbiologie
Médecine Aéronautique
Biochimie- Chimie
Radiologie
Chirurgie Pédiatrique
Pédiatrie
Radiologie
Chirurgie Plastique et Réparatrice
Urologie
Gastro-Entérologie
Anatomie Pathologique
Anesthésie Réanimation
Chirurgie Générale
Anatomie Pathologique

Anatomie Pathologique

Chirurgie pédiatrique
Anesthésie Réanimation
Traumatologie-orthopédie

**Enseignant militaire*

Pr. DRISSI Mohamed *
Pr. EL ALAOUI MHAMDI Mouna
Pr. EL OUAZZANI Hanane *
Pr. ER-RAJI Mounir
Pr. JAHID Ahmed

Anesthésie Réanimation
Chirurgie Générale
Pneumophtisiologie
Chirurgie Pédiatrique
Anatomie Pathologique

Février 2013

Pr.AHID Samir
Pr.AIT EL CADI Mina
Pr.AMRANI HANCHI Laila
Pr.AMOR Mourad
Pr.AWAB Almahdi
Pr.BELAYACHI Jihane
Pr.BELKHADIR Zakaria Houssain
Pr.BENCHEKROUN Laila
Pr.BENKIRANE Souad
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Pr.BOUATIA Mustapha
Pr.BOUABID Ahmed Salim*
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Pr.CHAIB Ali *
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Pr.DINI Nouzha *
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Pr.EL JAOUDI Rachid *
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Pr.EL KHLOUFI Samir
Pr.EL KORAICHI Alae
Pr.EN-NOUALI Hassane *
Pr.ERRGUIG Laila
Pr.FIKRI Meryem
Pr.GHFIR Imade
Pr.IMANE Zineb
Pr.IRAQI Hind
Pr.KABBAJ Hakima
Pr.KADIRI Mohamed *
Pr.LATIB Rachida
Pr.MAAMAR Mouna Fatima Zahra
Pr.MEDDAH Bouchra
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Pr.MRABTI Hind
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Pr.OUKABLI Mohamed *
Pr.RAHALI Younes
Pr.RATBI Ilham
Pr.RAHMANI Mounia
Pr.REDA Karim *

Pharmacologie
Toxicologie
Gastro-Entérologie
Anesthésie-Réanimation
Anesthésie-Réanimation
Réanimation Médicale
Anesthésie-Réanimation
Biochimie-Chimie
Hématologie
Anesthésie Réanimation
Néphrologie
Chimie Analytique et Bromatologie
Traumatologie orthopédie
Anatomie
Cardiologie
Réanimation Médicale
Pédiatrie
Anesthésie Réanimation
Radiologie
Neuro-chirurgie
Médecine Nucléaire
Chimie Thérapeutique
Toxicologie
Pédiatrie
Anatomie Pathologique
Anatomie
Anesthésie Réanimation
Radiologie
Physiologie
Radiologie
Médecine Nucléaire
Pédiatrie
Endocrinologie et maladies métaboliques
Microbiologie
Psychiatrie
Radiologie
Médecine Interne
Pharmacologie
Neuro-chirurgie
Oncologie Médicale
Pharmacognosie
Chirurgie Pédiatrique
Anatomie Pathologique
Pharmacie Galénique [Vice-Doyen à la Pharmacie](#)
Génétique
Neurologie
Ophtalmologie

**Enseignant militaire*

Pr.REGRAGUI Wafa
Pr.RKAIN Hanan
Pr.ROSTOM Samira
Pr.ROUAS Lamiaa
Pr.ROUIBAA Fedoua *
Pr SALIHOUN Mouna
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Pr.SEDDIK Hassan *
Pr.ZERHOUNI Hicham
Pr.ZINE Ali *

Neurologie
Physiologie
Rhumatologie
Anatomie Pathologique
Gastro-Entérologie
Gastro-Entérologie
Chirurgie Cardio-Vasculaire
Gastro-Entérologie
Chirurgie Pédiatrique
Traumatologie Orthopédie

Avril 2013

Pr.EL KHATIB MOHAMED KARIM *

Stomatologie et Chirurgie Maxillo-faciale

Mai 2013

Pr. BOUSLIMAN Yassir*

Toxicologie

Mars 2014

Pr. ACHIR Abdellah
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Pr. MAKRAM Sanaa *
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Chirurgie Thoracique
Traumatologie- Orthopédie
Chirurgie Thoracique
Néphrologie
Biochimie-Chimie
Histologie- Embryologie-Cytogénétique
Pédiatrie
Pneumologie
Hématologie Biologique
Gynécologie-Obstétrique
Pharmacologie
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Médecine Interne
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Décembre 2014

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Dedications



To my beloved mother and father, Khadija & Ahmed

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List of abbreviations



Abbreviations

ABG	: Arterial Blood Gases
ACLS	: Advanced Cardiac Life Support
AED	: Automated External Defibrillator
AHA	: American Heart Association
BP	: Blood Pressure
BPM	: Beats per minute
BIS	: Bispectral Index
CBF	: Cerebral Blood Flow
CN	: Cranial Nerve
CPR	: Cardiopulmonary Resuscitation
CSF	: CerebroSpinal Fluid
EAV	: Expired air ventilation
EBA	: European Board of Anaesthesiology
ESA	: European Society of Anesthesia
ETCO₂	: End-Tidal Carbon Dioxide
ETT	: Endotracheal Tube
ERC	: European Resuscitation Council
GVR	: Glossopharyngeal Vagal Reflex
ROSC	: Return of Spontaneous Circulation
ICP	: Intracranial Pressure
IOCA	: Intraoperative Cardiac Arrest
IOH	: Intraoperative Hypotension
IHCA	: In-Hospital Cardiac Arrest

ILCOR	: International Liaison Committee on Resuscitation
INSERM	: Institut national de la santé et de la recherche médicale
LMIC	: Low-Middle Income Countries
LV	: Left Ventricle
MAP	: Mean Arterial Pressure
MCCE	: Major adverse cardiovascular and cerebrovascular events
NIBP	: Non-Invasive Blood Pressure
OCR	: Occulo-Cardiac Reflex
OHCA	: Out-of-Hospital Cardiac Arrest
OR	: Operating Room
PEA	: Pulseless Electrical Activity
PPCA	: Periprocedural Cardiac Arrest
PVC	: Premature ventricular contraction
RCT	: Randomized Clinical Trial
ROSC	: Return of Spontaneous Circulation
SFAR	: Société Française d'Anesthésie Réanimation
STEMI	: ST-elevated myocardial infarction
TCR	: Trigemino-Cardiac Reflex
TTE	: Trans-Thoracic Echocardiography
TTS	: Takotsubo Syndrome
VF	: Ventricular Fibrillation
VT	: Ventricular Tachycardia
ICA	: Intraoperative cardiac arrest
WHO	: World Health Organisation



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Introduction



During the last decade, the volume of global surgical procedures grew in numbers (1). WHO and the World Bank data showed that the burden of surgical diseases would eclipse that of HIV, tuberculosis, and malaria by the year 2026 (2). The World is in great need, as it requires more than 321,5 Million Surgical procedures to respond to a global population in continuous growth, and this surgical need differs from one region to another but is highly marked in Sub-Saharan Africa (3).

With this increasing volume of surgeries, comes the necessity to discuss the patients' safety, as, despite all initiatives and efforts to promote it, such as the implementation of the WHO Safe Surgery Saves Live Initiative and Checklists (4) and the publishing of the International Standards for Safe Practice of Anaesthesia by The World Federation of Societies of Anesthesiologists (5), we are witnessing stagnation and relapse in access to Safe Anesthesia and Surgery, especially in Low and Middle-Income Countries (6). The Lancet Commission on Global Surgery also shared the necessity to strengthen data collection and to conduct more work to widen our understanding of this global phenomenon, and advocated to include perioperative mortality as an important health indicator and announced that 80% of countries by 2020 and 100% of countries by 2030 will be tracking perioperative mortality (6).

“Primum Non Nocere”, this fundamental ethical principle is at the core of the Helsinki Declaration, a document developed jointly by the European Society of Anaesthesiology (ESA) and the European Board of Anaesthesiology (EBA). The Helsinki Declaration recommends practical immediate steps that can enhance patients' safety, the declaration also reiterates the importance to abide by and support other important safety protocols from WHO, including the Safe Surgery Checklist (7). This document was signed and endorsed by Morocco in 2015 (Appendix 2).

According to the last 2020 American Health Association Heart Disease and Stroke Statistics—2020 Update (8), In the United States of America, the Cardiac Arrest incidence is estimated at 110.8 individuals per 100 000 population, with only 22% of survival to hospital admission of Out-of-Hospital Cardiac Arrest who received CPR, and only 8,8% at hospital discharge (9). These numbers differ from a country to another, and a Moroccan paper showed an inferior rate of only 4,9% (10). On the other hand; the survival rate is better for In-Hospital Cardiac Arrest with 25,8% Survival Rate at hospital discharge (8) and it's mainly due to the availability of Cardiopulmonary resuscitation equipment, the closed and monitored environment, and the well-trained staff that can timely detect, initiates, and sustains an efficient CPR. Perioperative Cardiac Arrest is even a more rare form of intra-hospital cardiac arrest as it only constitutes 2% of all IHCA, and studies about these forms are very limited (11)(12). To this date, it is difficult to find strong and multicentric evidence about the Perioperative Cardiac Arrest in Neurosurgery, However, a literature review showed that this event is special and its managements should be adapted to the aetiology (13)

Cardiac Arrest is a dreadful adverse event and can lead to severe outcomes, and thus the necessity to understand its etiopathogenesis, and management especially in a Neurosurgical setting, where conventional Advanced Cardiac Life Support (ACLS) algorithms are hard to apply. The Cardiac Arrest in Elective Neurosurgery, is complex and different from other types, as it's influenced by the patient's position, the surgical procedure, and the equipment used to fix the skull (14); the position for exemple can hinder the execution of a normal CPR or delay it, thus it is important to reflect and propose clear guidelines adapted to these situations. Our work is a retrospective study about Perioperative Cardiac arrest (Including Ventricular Fibrillation, Ventricular Tachycardia, and Pulseless Electrical Activity) and other Severe Perioperative cardiac complications (Severe Bradycardia, Hypotension) in Elective Neurosurgery, with the aim to understand the epidemiology and the factors influencing mortality and morbidity.



Methods and Measures



We performed a retrospective and observational study involving patients admitted for intracranial surgery at the operating room of the Mohammed V Military Hospital in Rabat. Our first objective is to determine the incidence and types of severe cardiac complications occurring during the intracranial procedure. Secondly, we proceed to a literature review and proposed evidence-based recommendations for the management of these adverse events.

I. About the Study

A. Introduction

This is a retrospective study of severe cardiac complications occurring during intraoperative intracranial neurosurgery. This study was done in the operating center of the Mohammed V Military Hospital in Rabat, over a period of 3 years, going from the beginning of February 2017 until the end of December 2019.

The UMIMV Operating center includes 12 Intensive Units beds, divided in 12 individual boxes. The ICU welcomes postoperative scheduled and emergency surgery for all specialities including neurosurgery. The department is led by two Professors, two specialist registrars, and a team of interns and residents in Anesthesia and Intensive care. The paramedical team is made up of a senior nurse, 16 general nurses, a physiotherapist and 4 service agents.

B. Target Population

This study screened all patients admitted to the operating room of the Mohammed V Military Instruction Hospital, from February 2017 to December 2019

C. Inclusion Criteria

We adopted as inclusion criteria: all neurosurgery patients who benefited from a scheduled craniotomy.

D. Exclusion Criteria

Were excluded from this study, patients operated on for traumatic brain injuries and patients under 18 years old.

E. Definition

We defined severe cardiac adverse events as any adverse event including ventricular fibrillation, pulseless electrical activity, asystole, or severe bradycardia (<40 / min) with hypotension.

II. Data Collection

All the Medical Records of patients included in this study during the study period were analyzed using a data collection form.

A. Patient's Characteristics and epidemiological data: Age, Sex

B. Patients' comorbidities and medical history : Represented by the patient's medical history and the presence of a chronic disease and comorbidities. The analysis included:

- Cardiovascular diseases: Arterial hypertension, heart failure, valve disease, coronary artery accident. And Diabetes.
- Respiratory diseases: Chronic Obstructive Pulmonary Disease.
- Bleeding disorders, and on-going anticoagulant treatment.

C. ASA Classification

D. Operating position

E. Complications



Results



I. Descriptive Analysis

In a 3 years period, 226 patients were admitted for intracranial neurosurgery in our Operating Rooms. A total Number of **196 patients responded to our inclusion criteria** and were screened to be part of this study. 20 Patients were excluded, including 14 Patients as their data couldn't be collected, and 6 Patients as they were under 18 years.

Table I : Patients admitted to the Operating Room for an Intracranial Neurosurgery

Total number of patients admitted for an intracranial neurosurgery	216
Number of included patients in the study	196
Number of Excluded patients	30

A.Flow Chart

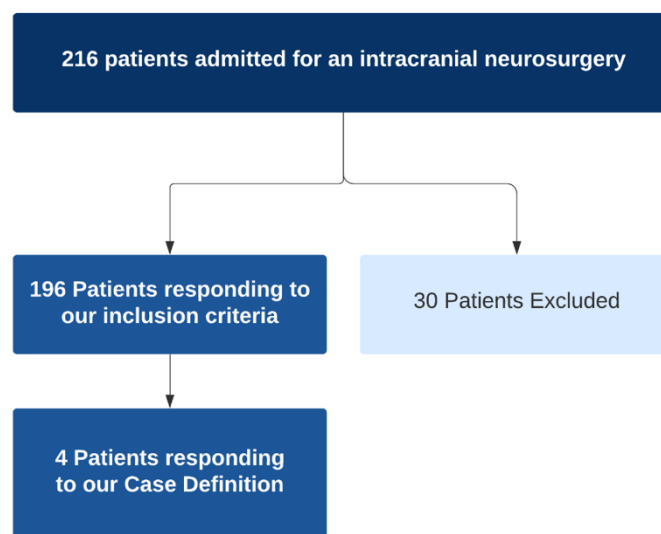


Figure 1 : Study patients' flowchart

B. Study Population' Characteristics

1. Age :

The Mean Age of the Study population is 55,8 with the youngest patient being 19 years old, and the oldest being 76 years old.

Table II: Age Groups and Age Distribution

Age Range	Number of Patients	Percentage
18-25	8	4%
25-35	16	8%
35-45	31	16%
45-55	49	25%
55-65	61	31%
> 65	31	16%

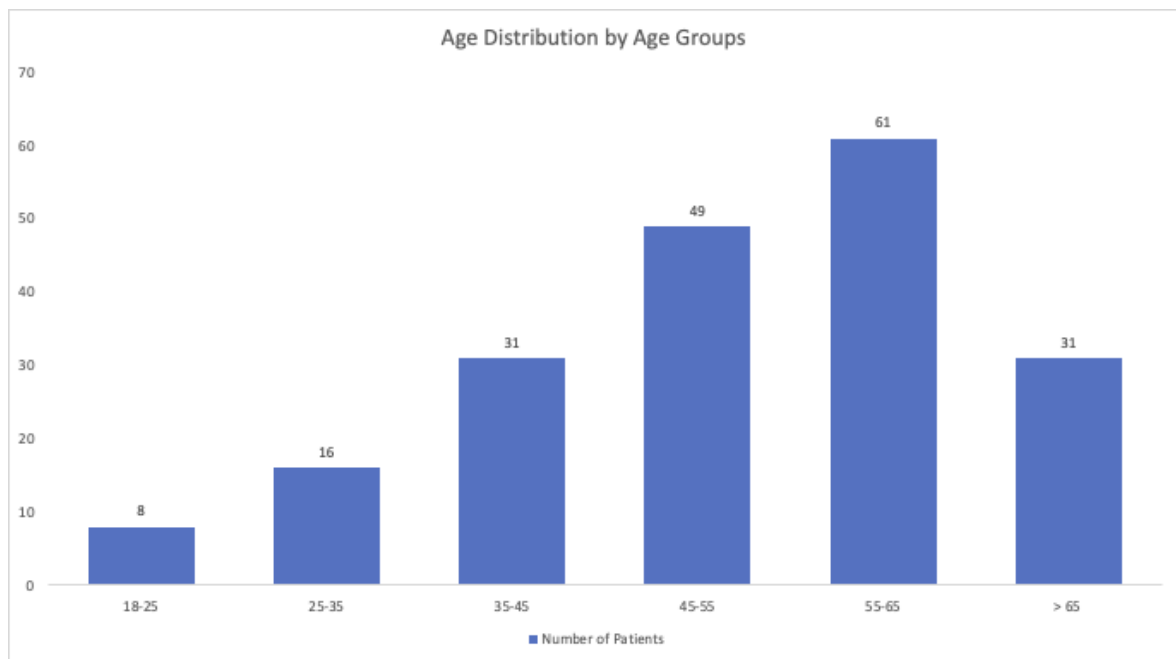


Figure 2: Age distribution by age groups

2. Gender :

The Masculine Gender is predominant with 56,1 % for Masculine. The Sex Ratio (M/F) is 1,27 for Masculine, with 110 Masculine Patients , and 86 Feminine Patients.

Table III: Gender Distribution in our Population

Gender	Number of Patients	Percentage %
Male	110	56,1%
Female	86	43,9%

Gender Distribution in Patients

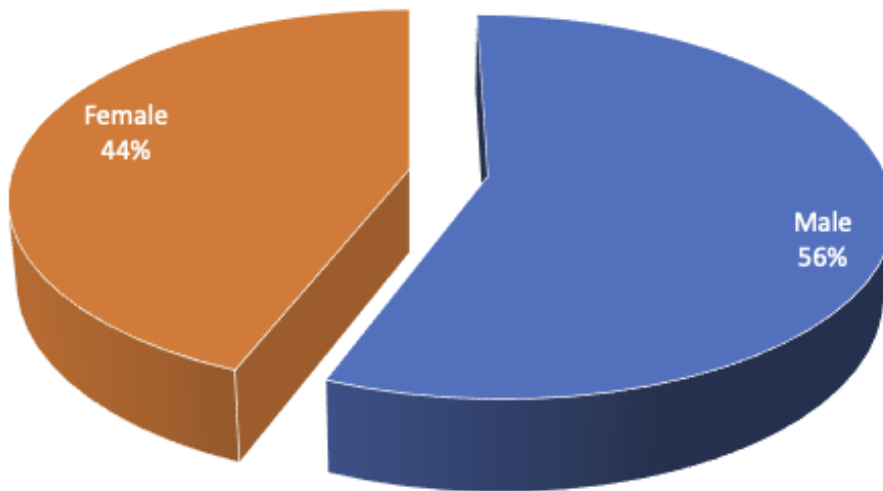


Figure 3: Gender Distribution among our patients

C.Study of Patients' comorbidities and medical history

1. Medical and Surgical History

102 patients (52%) had no specific medical history, 94 patients (48%) however had at least one medical or surgical history or associated comorbidity.

Table IV: Distribution of Medical and Surgical History

Medical and Surgical History	Number of Patients	Percentage %
Absent - No	102	52%
Present Yes	94	48%

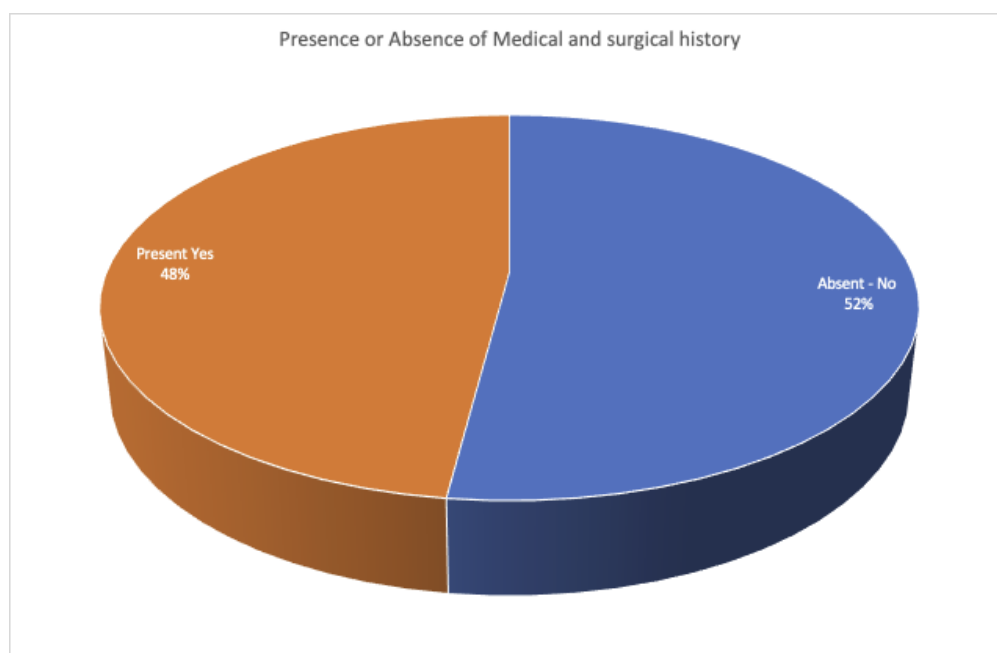


Figure 4: Distribution of Medical and Surgical History among our patients

2. ASA Classification

Initial ASA Classification, showed that all our patients are in ASA I, II, and III Groups. With 38 patients (19%) in ASA I group, 97 patients (50%) in ASA II, and 61 Patients (31%) in ASA III group.

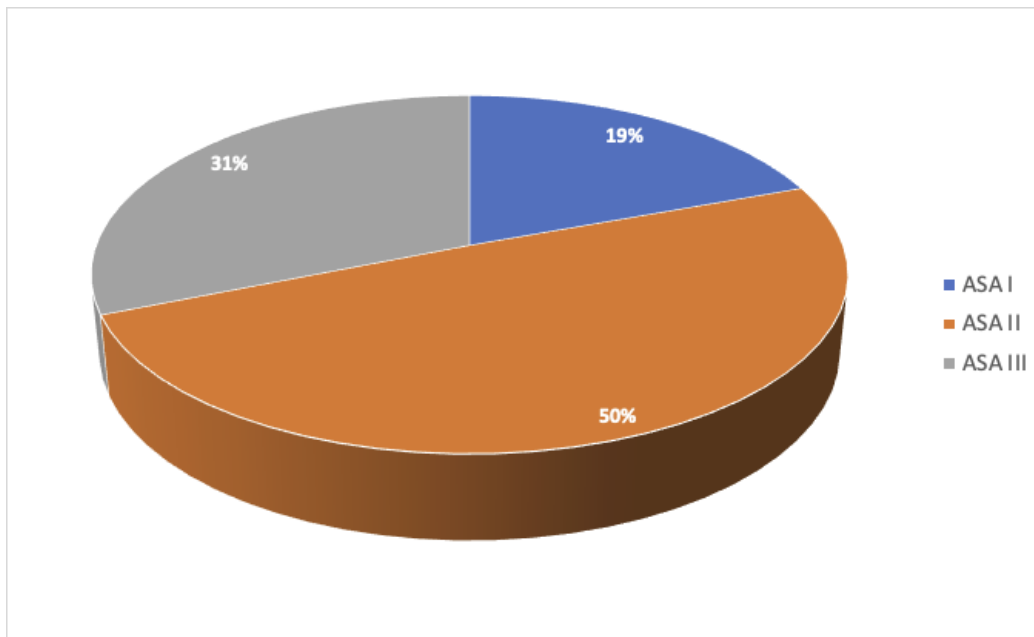


Figure 5: Distribution of ASA Classification in our patients.



Patient's Observation



I. Patient Number 1 :

A.Observation

A 40-year-old patient, weighing 65 kg, was admitted to the neurosurgery department for occipital headache accompanied by vomiting and reduced visual acuity that had progressed in the past 9 months. He had no specific history nor had any comorbidities. All the requested radiological and biological assessments that were carried out were within normal limits. The patient was diagnosed on MRI with a dermoid cyst in the magna cistern displacing the fourth ventricle; therefore, a retro mastoid suboccipital craniotomy and tumor excision were planned.

After admission to the operating room, we proceeded with the induction with 200 µg intravenous Fentanyl and 160 mg Propofol. Orotracheal intubation was facilitated by the administration of 100 mg of rocuronium intravenously. The anesthesia was maintained with sevoflurane in a mixture of oxygen and nitrous oxide (50/50) as well as with intermittent boluses of fentanyl 1 µg / kg and rocuronium 0.2 mg / kg depending on the needs. The patient was placed prone and the operation started.

After 90 minutes the Anesthesiologist and the nurse were alerted by sudden asystole without any prior prodrome which spontaneously resolved followed by a transient episode of bradycardia which occurred which also resolved spontaneously. 8 minutes later, a second episode of bradycardia occurred and was complicated by a new asystole. The neurosurgeon was notified and 0.5 mg of atropine was administered intravenously. The heart rate has returned to normal. Mean arterial pressure (MAP) dropped from 80 to 50 mm Hg. A bolus of neosynephrine (3 mg) was given. The mean arterial pressure increased to 85

mm Hg and tumor dissection was resumed. Another episode of sudden asystole occurred four minutes later and Heart rate increased after stopping the stimulus. The bradycardia stopped with the surgical stimuli stopping, indicating that the surgical manipulation of the brain was the probable cause. After this event, it was decided to end the operation and resume it later. The operation continued afterwards and took place without significant incidents. The patient was subsequently transferred to intensive care for postoperative monitoring and he was extubated without any incident 8 hours later and he returned to the ward after an 18-hour stay in intensive care.

B. Discussion

Cardiac pathology, hypoxia, insufficient anesthesia, the use of agents such as β -blockers, α_2 -agonists, strong narcotics and other anesthetic drugs can all lead to bradycardia or asystole during an ongoing operation. Asystole can also be produced by paradoxical cardiovascular reflexes (15). Neurogenic bradycardia which can lead to cardiac arrest is a rare, but well-recognized complication of anesthesia. Acute increase in intracranial pressure and subsequent secondary compression of the brainstem may be the cause. Sometimes it can be secondary to vagal stimulation caused by an injury to the spinal cord.

These reactions can also be caused by activation of the trigeminal cardiac reflex due to direct stimulation of the trigeminal nerve or its branches in the dura mater or the cerebellar tentorium (16). The trigeminal nerve and the cardio-inhibitory vagus nerve constitute the afferent and efferent pathways of the reflex arc. Sudden asystole occurs regardless of the pressure exerted on the brainstem during posterior fossa surgery which remains the only explanation in our case.

With the removal of the surgical stimulus, bradycardia usually improves and pharmacological treatment is not necessary, with direct manipulation of the brainstem. The drugs given may mask the signs of brainstem manipulation and permanently damage the cranial nerve nuclei. The ability to predict the risk of asystole can better prepare the anesthesia team to anticipate, identify and manage an episode. The importance of having the knowledge, vigilance, equipment and skills to quickly deal with such a case will be critical to the survival of the patient.

Intraoperative cardiac arrest in patients placed in a position other than supine poses a challenge in terms of resuscitation. Here, the patient was operated in a lateral position. Repositioning these patients is difficult, as it not only requires manpower to return the patient to a supine position safely, but also delays cardiopulmonary resuscitation. Otherwise, resuscitation should be performed in unconventional positions (17).

II. Patient Number 2 :

A. Observation

A 45-year-old patient was admitted to the neurosurgery department for a reduced unilateral vision in her right eye evolving for more than 4 months. Magnetic resonance imaging revealed a homogeneous mass of 2×2 cm over the suprasellar region. The patient was diagnosed with suprasellar meningioma and a bi-frontal craniotomy with tumor excision was planned in a supine position.

All preoperative examinations, including the EKG and Chest X-Ray, were normal. On the day of the operation, the patient was pre-medicated with 0.2 mg of glycopyrrolate intramuscularly one hour before the operation. Routine monitors have been set up. The basal heart rate was 78 bpm and the blood pressure was 130/80 mmHg. General anesthesia was induced with fentanyl $2 \mu\text{g} / \text{kg}$, propofol $1.5 \text{ mg} / \text{kg}$ and tracheal intubation was facilitated with rocuronium $1 \text{ mg} / \text{kg}$. The trachea was intubated using a 7.5 mm cuff portex endotracheal tube. Anesthesia was maintained with sevoflurane in a mixture of oxygen and nitrous oxide (50:50) and intermittent boluses of fentanyl and vecuronium as needed. Dexmedetomidine was also administered just before the incision (1 bolus of $\mu\text{g} / \text{kg}$ over 10 min followed by an infusion of $0.4\text{-}0.5 \mu\text{g} / \text{kg} / \text{min}$). Invasive intraoperative monitoring was established and included central venous pressure and arterial pressure, using the right femoral vein and left artery, respectively. The patient was maintained at a mean arterial pressure of 65-70 mmHg.

During retro chiasmatic dissection, a sudden severe bradycardia (30 beats / min) with hypotension (mean arterial pressure 50 mmHg) occurred. The surgeon

was immediately informed. After removing the stimulus, the heart rate and blood pressure returned to normal. These transient hemodynamic disturbances occurred twice. No pharmacological intervention was performed. After this excision cardiac event, the operation took place without any other incident.

The patient was transferred to the intensive care unit for elective ventilation. The next day, the trachea was extubated while the patient was fully conscious and following orders.

B. Discussion

Hemodynamic disturbances in neurosurgical patients frequently occur due to increased intracranial pressure, trigeminal-cardiac reflex, vagal stimulation, and stimulation of the floor of the fourth ventricle. Hypothalamic stimulation is responsible for the production of a wide range of dysfunctions of the cardiovascular system. Since the hypothalamus is located in close proximity in the suprasellar compartment, it is likely that it produces such an event in this patient. A similar hemodynamic event has been reported with hydrogen peroxide irrigation in craniopharyngioma surgery. The anterior hypothalamus participates in the baroreflex regulation of the heart rate by modifying the parasympathetic tone but without affecting the activity of the cardiac sympathetic nerve. The stimulus from the anterior hypothalamus therefore probably contributed to severe bradycardia and hypotension in our patient.

In conclusion, any surgery in the suprasellar region can produce similar symptoms due to manipulation of the anterior hypothalamus, but immediate stop of these stimuli usually aborts these hemodynamic disturbances and generally does not require active pharmacological intervention.

III. Patient Number 3 :

A.Observation

Mrs. F.F., 51 years old, 1.68 m tall and weighing 72 kg, G3P3, was admitted to the operating room for the management of a left frontotemporal meningioma. The patient had no previous medical history. Her history of the disease started 9 months ago, with the progressive onset of headaches associated with tingling of the right upper limb, without any notion of convulsions or other associated signs. Brain MRI showed the presence of a left fronto-temporal meningioma, and the indication for surgery was given.

The patient was admitted to the operating room and monitored with a 5-lead cardioscope, blood pressure cuff and pulse oximetry. A 16G peripheral venous line (PVL) was established, connected to 0.9% saline. After pre-oxygenation and vascular filling, induction was performed with 250g fentanyl, 120mg propofol and 50mg rocuronium. After 3 min, orotracheal intubation was performed with a 7.5 mm armed tube connected to the anesthesia machine, with a tidal volume (Vt) of 480 ml, respiratory rate at 12 cycles/min, fraction of inspired oxygen (FiO₂) at 50% and positive expiratory pressure (PEP) at 5 cmH₂O. Anesthesia was maintained with sevoflurane at 1 MAC.

A right radial arterial catheter was placed for invasive blood pressure monitoring as well as a right femoral central venous line and a urinary catheter. The operative procedure consisted of a craniotomy with resection of the meningioma. Intraoperatively, hemodynamic stability was achieved (BP = 120/60cmHg - CF = 90bpm), cerebral relaxation was achieved with 20% mannitol (60 g or 3 mmol) with 20 mg furosemide and 120 mg

methylprednisolone. Bleeding was estimated at 1200 ml, compensated by transfusion of 4 red blood cells. After tumor resection and towards the end of the procedure, the patient presented hemodynamic instability with nonsustained tachycardia and a sharp drop in blood pressure (HR= 140 bpm, BP = 70/40 cmHg) without any hemorrhagic signs or respiratory alterations.

Arterial Gasometry showed pH 7.35, PaO₂ 100 mmHg, PaCO₂ 32 mmHg, HCO₃ 24 mmol and hematocrit 35%. Norepinephrine was started at a dose of 0.5g/kg/min and the patient was admitted to the ICU for further management. In the intensive care unit, the ECG showed a regular sinus rhythm with the presence of an anterosepto-apical ST elevation. Troponin was 120 times the normal value. The rest of the biological tests were normal.

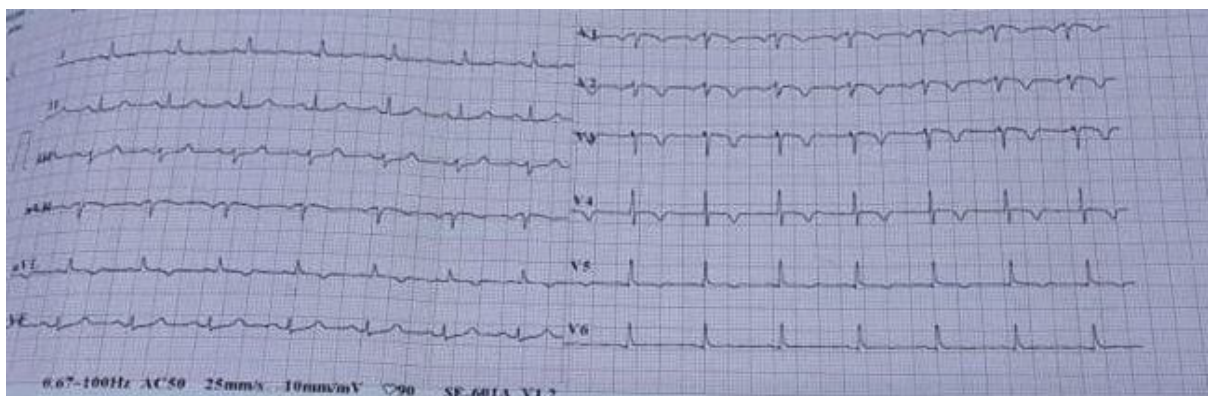


Figure 6: Electrocardiogram showing the ST elevation in our patient

Before the echocardiography and in front of the picture of postoperative arterial hypotension, the following differential diagnoses were evoked: hypovolemia, significant vasoplegia (sepsis), left and/or right ventricular dysfunction, acute ischemia, dynamic subaortic stenosis, compression by tamponade or pneumothorax. TTE showed apical ballooning with global LV akinesia and an estimated LVEF of 18%.



Figure 7: TTE Image showing apical ballooning in our Patient

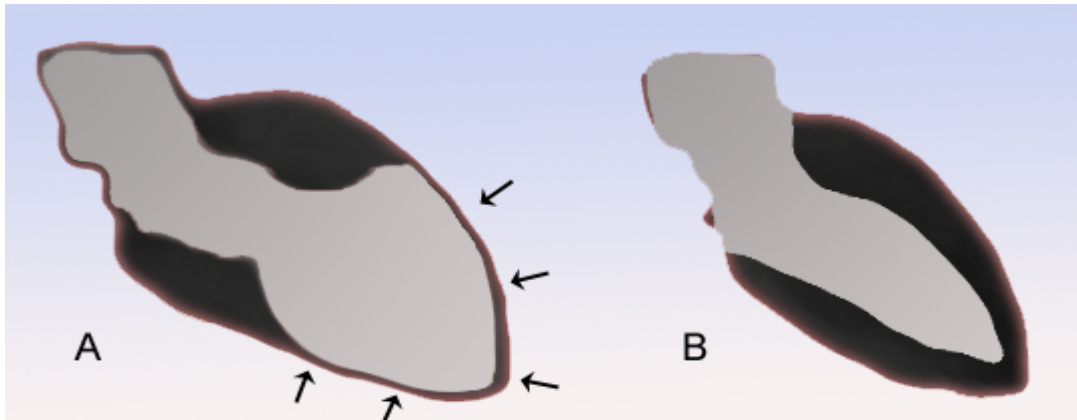


Figure 8: Illustration of Takotsubo Cardiomyopathy

Based on the ultrasound appearance and ECG data, the diagnosis of Takotsubo syndrome was made. Achieving a correct hemodynamic state required increasing the doses of norepinephrine to 1 g/kg/min.

Coronary angiography was not performed because of the risk of hemorrhage associated with the use of heparin. The evolution was marked by a progressive fall in troponin levels until its normalization, as well as regression of the ST elevation on repeated ECGs. A follow-up transthoracic echocardiography was performed on the 3rd and 7th day. A progressive improvement of the LVEF was found (respectively 40 and 56%). The patient was discharged after 3 weeks, after global recovery of cardiac and neurological functions.

B. Discussion

Takotsubo cardiomyopathy (TC) or Takotsubo syndrome (TTS), is a type of non-ischemic cardiomyopathy with an associated acute cardiac heart failure. Catecholamines are the main responsible of the pathophysiology of the TC, that's why it's called stress cardiomyopathy. The TTS was described 25 years ago by Japanese teams, who described the heart as a “Tako” “Tsubo” , the Octopus pot that resembles the heart and LV shape in TTE .

It is a cardiac pathology characterized by apical or mid-apical akinesis of the left ventricle. It mimics an acute coronary syndrome, with electrocardiographic signs from STEMI, an increase in cardiac enzymes, but with an absence of abnormalities on the coronary angiography (absence of angiographically significant coronary stenosis). It is defined by reversible myocardial astonishment. The lack of complete recovery from ventricular dysfunction rules out this diagnosis (18). TS is manifested by ECG signs or abnormal left ventricular wall movement, release of myocardial enzymes, and increased BNP. In electrocardiography, differences with prolongation of the QT interval, ST segment depression, long QT syndrome, T wave inversion and numerous arrhythmias in the TC were recognized in the study de Backer O et al, an elevation of ST was seen in 53.1% of patients with CT, while depression of ST / T negative was seen in 43.8% of them (19). ECG abnormalities occur in 25 to 75% of patients with Subarachnoid Bleeding, while arrhythmias have been recorded in all of these patients. Moreover Póvoa R et al reported that in 3% of patients with intracranial tumors an elevation of ST was observed (20).

A multi-centric study including more than 26 centers of the International Takotsubo registry showed that TC has an hospital death rate of 4.1% and an inpatient death rate at 30 days at the 5.9% level (21). The study also found that in the TC patients population (n=1750), 46.8% of patients of them suffered from neurological and psychiatric disorders (9.4% of patients with acute neurological disorders, 19.4% with chronic neurological disorders). The TC was also associated with coronary heart disease, as 15.3% of TC patients had a history of coronary disease (19).

The TC can be observed in physical, acute neurological lesions (with or without intracranial hypertension) such as a head trauma, an ischemic or hemorrhagic attack, in particular a subarachnoid hemorrhage (SAH), infections of the central nervous system as well as after epileptic seizures (22). Thus, Physical and emotional stress is responsible for CT, as described in other studies (19).

A differential diagnosis between TC and acute coronary syndrome must always be established. In our case, it could not be such a mechanism that led to this pathological entity. Nevertheless, it has been observed that TC can occur during the perioperative period (also under anesthesia) due to stimulation of sympathetic stress reflexes, increased epinephrine levels, anaphylaxis and activation of the so-called histamine-adrenergic cross-dialogue (23). TC usually occurs in patients with subarachnoid hemorrhage the day after the bleeding. In contrast, TC has also been diagnosed in patients with hydrocephalus.

IV. Patient Number 4 :

A.Observation

A 58-year-old woman, 165 cm tall and weighing 78 kg, was suffering from headache and seizures for 4 months. Diagnosis confirmed a right temporal lobe glioma. She was then scheduled for craniotomy and tumor resection under general anesthesia. The patient had a medical history of hypertension treated by calcium channel blockers; she was also under sodium valproate for the seizures. The preoperative checkup did not diagnose any problem, in particular the preoperative ECG and the other laboratory tests, blood ionogram, the renal function, the glycemia were all normal.

On admission to the operating room, the patient's hemodynamic status was stable. Anesthesia was induced with Propofol (100 mg) and fentanyl (200 µg/), and for intubation rocuronium was added (50 mg). The anesthesia was maintained with sevoflurane (1.2-1.5%). Twenty five (25) minutes after the surgical incision, 200 ml of 20% mannitol (40 g) was administered intravenously over 60 min. Approximately 20 min after the end of mannitol administration, a Ventricular Tachycardia occurred (Figure XX).

At this time, in the operative field, the arachnoid membrane of the Sylvian fissure was separated. Blood pressure decreased to <40 mmHg. We immediately started the chest compression, and the VT recovered to sinus rhythm at a rate of 75 bpm approximately 20 s after the start of the chest compressions. After recovery of sinus rhythm, ECG did not show noticeable abnormalities. Analysis of arterial blood gases showed pH 7.38, PaCO₂ of 40 mmHg, PaO₂ of 350 mmHg, ionogram revealed hyperkalemia of 5.5 mmol/L. The glucose serum was

administered with 10 units of insulin. The control value of kalemia was 3.6 mmol/L. Tumor resection was performed without any further incident nor hemodynamic instability. At the end of the operation, no abnormalities were described in the ECG and laboratory tests. The duration of the surgical intervention was 4 h 20 min the estimated blood loss during the operation was 300 ml. The urine output was 2000 ml. The patient had no other postoperative event and was admitted to intensive care for postoperative care. The patient was extubated after full recovery.

B. Discussion

In this case, VT occurred without prior ECG change despite hyperkalaemia due to mannitol. Fatal arrhythmia often occurs during neurosurgery. In general, there have been cases during surgeries during craniotomies. There are a few reports of fatal arrhythmia, VT and / or ventricular fibrillation due to mannitol, which are mainly due to hyperkalemia (24) (25).

Mannitol is widely used to reduce intracranial pressure due to increased osmolality of plasma. However, it has several side effects including osmotic nephrosis and electrolyte disorders (26). Rapid infusion of mannitol may cause hyponatremia or hyperkalaemia. Hyponatremia is mainly due to transient dilution. During mannitol-induced hyperkalemia, intracellular potassium (K) is released into the extracellular space due to an acute increase in plasma osmolality, rhabdomyolysis, hemolysis, and acidosis. In this case, preoperative renal function was normal and there was no evidence of acidosis, rhabdomyolysis or hemolysis. The frequency of mannitol-induced hyperkalemia is 7.7%, and the total dose of mannitol as well as its rate of infusion and decreased renal function may have a role in the development of mannitol-

induced hyperkalemia mannitol (27). We used a total dose of 40 g of mannitol, which was the recommended dose (0.25-1 g/kg) (28), And the infusion rate was 60 minutes, which was not rapid. In most of the published cases, the change in the ECG - elevation of T waves - was the main finding.

All cases of lethal arrhythmia reported so far have been preceded by a change in the ECG, including elevated T waves and a wide QRS complex. However, no prior ECG changes were observed in our patient, and even after returning to sinus rhythm after VT. Regarding ECG changes in hyperkalemia, such as elevation of T wave (temporary T wave), decrease of P wave, prolongation of PQ interval due to an increase in the kaleemia the extension of the width of the QRS, the disappearance of the P wave and its subsequent increase which leads to an unclear distinction between the QRS and T waves, leading to the cessation of activity cardiac mechanics (29).

However, an ECG without any abnormalities consistent with hyperkalemia is noted in more than 50% of patients with a $K > 6.5$ mmol/L, and cases of arrhythmia and cardiac arrest have been reported in patients with of hyperkalaemia without ample T wave (30) (31). It is not clear why the VT occurred in our case, but in addition to the transient elevation of potassium and mannitol, the craniotomy itself may have influenced it. Therefore, anesthetists and neurosurgeons should be aware that fatal arrhythmia can occur due to mannitol-induced hyperkalemia.



Discussion



I. Historic Introduction about Cranial Surgery and Neuroanesthesia

Originating from the Prehistoric times, neurosurgery is one of the most ancient forms of Medicine and Surgery. Crane trepanation was reported to be the first neurosurgical technique (32). It was used chiefly for the treatment of headaches, seizures, CNS disorders, and accidental brain damages. Craniotomy procedures were described in the Incas population and a record of the neurosurgical operation can be visualised on Egyptian papyri (33).

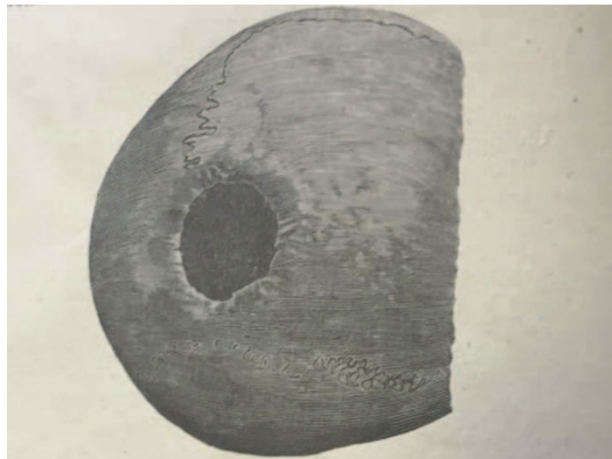


Figure 9: Trepanation in the Incas Population. Journal of Forensic Psychiatry, Criminal Anthropology and Related Sciences 1908, 5:41-50

It's also important to cover the “Golden age” of medicine and neurosurgery field in the Greek with Hippocrates (34), who contributed enormously to the management of traumatic brain injuries (35), and the treatment of subarachnoid haemorrhage, and prepared the first documented suggestion for the use of a threpanon. Moving forward in history, the Arab Scientists played a major role in the growth of this topic, Ibn Sina and Rhazes revolutionized the European universities with their contributions (17), but Albucasis was the one who truly

influenced the field neurosurgery with his devotion to write more than 30 volume of his tritise to cover neurosurgical pathology, its treatment, instruments and neurosurgical techniques (36).

Despite growth in these centuries, progress was truly initiated after the 16th century when Leonardo da Vinci described head anatomy and Berengario da Carpi wrote the first book on head trauma with illustrations (37). Even greater expansion was seen in the 16th century, when progress was seen at the academic level, enhancement in anatomical knowledge, the identification of Willis's circle and vascular supply of the brain; operation and procedures on intracranial hemorrhage; first thorough explanation of surgical tools and head trauma in children. Lastly, but not least, for the first time in the 18th century a surgery on brain abscess was performed, with thorough description of the cerebrospinal fluid (38). Another major evolution in medicine occurred with Ambrose Paré, who rejected the practice of boiling oil for cautery and suggested vascular ligatures. Cautery will return later starting in the 19th century with the electrocautery devices popularized by T.Bovie.

Modern neurosurgery started with Cushing in the United States, in the 1900' despite the fact that neurosurgical procedures have been conducted since ancient times. Cushing is considered as the Father of Modern Neurosurgery, and was able to provide a much comprehensive explanation of the pathophysiology of Cushing's reflex (39), including the timings, phases, and local variations of the observations associated with increased brain pressure. He described that increased intracranial pressure caused by cerebral herniation and brainstem compression resulted in increased systolic blood pressure, as well as bradycardia and respiratory irregularity.

Modern neurosurgery arose after two revolutions, namely the development of infection prevention and control and the possibility to conduct general anesthesia, as Ether and chloroform were discovered in the 18th century, resulting in an enormous advance in the field of neuroanesthesia. Also, the 18th century saw the discovery of carbon dioxide, which led to the investigation of its new qualities and uses, and in the 19th century, such as the one of oxygen was discovered, nitrogen and nitrous oxide (16). But it was in Massachusetts General Hospital , that Wells and Morton successfully demonstrated the use of ether for general anesthesia.



Figure 10: Re-enactment of the first public demonstration of general anesthesia by William T. G. Morton on October 16, 1846 in the Ether Dome at Massachusetts General Hospital, Boston.

The other important advancement was the development in infection prevention and control. Since the beginning of time, doctors have tried to understand the asepsis. Early on, antiseptic technique was not understood as microorganisms were not discovered until the 17th Century with the development of the Microscope (40). But advancement by different scientists like Pasteur, Ignaz Semmelweis and Robert Koch initiated the principles in IPC, from handwashing to disinfection and sterilisation (41).

II. Patients' Safety in Neurosurgery

One of the essential foundations of medicine is the “Primum non nocere” or “First, No Harm” principle in the provision of safe treatment for all those in need. Because of its high degree of complexity, neurosurgery is considered high-risk surgery, and improving patient outcomes has always been a primary focus of the specialty's research. On the other hand, The need for a systematic strategy to increase patient safety and lowering adverse events has just lately been recognized as a necessity (42). Working on mitigating adverse events and promoting patients safety can only be done through multimodal initiatives including quality studies. These studies should be based on a comprehensive data collection, adverse event definitions, and systematic data analysis.

Patient safety employs the safety-science models to study healthcare systems and analyse adverse events, errors and suggest harm-minimisation approaches. Avedis Do-nabedian introduced a systematic method to health system analysis in 1966. In this methodology, quality measures were divided into three parts: structure, process and outcome.



These three components of quality measurement interact to refer to the structure as facilities and environment, process as the ensemble of clinical and medical interventions including surgery and anesthesia care and outcome as the final result, either recovery, survival or mortality. This matrix allowed for a deep examination of mis-steps that can harm patient safety. Another interesting model to study is the "Swiss Cheese Model" as described by James Reason. In this framework, harm to the patient can only occur if several system failures occur and align (43) (Figure11) . This model reinforces this holistic understanding of losses and highlights the role of teams and collaboration (eg. in the Operating room between the surgeon, the anesthetists, and the allied health care workers).

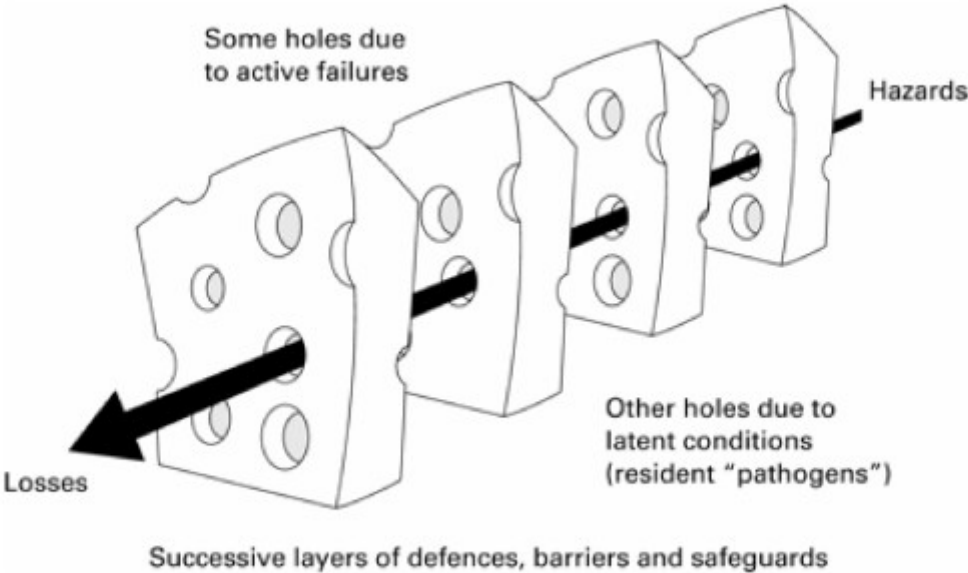


Figure 11: Swiss Cheese Model by James Reason

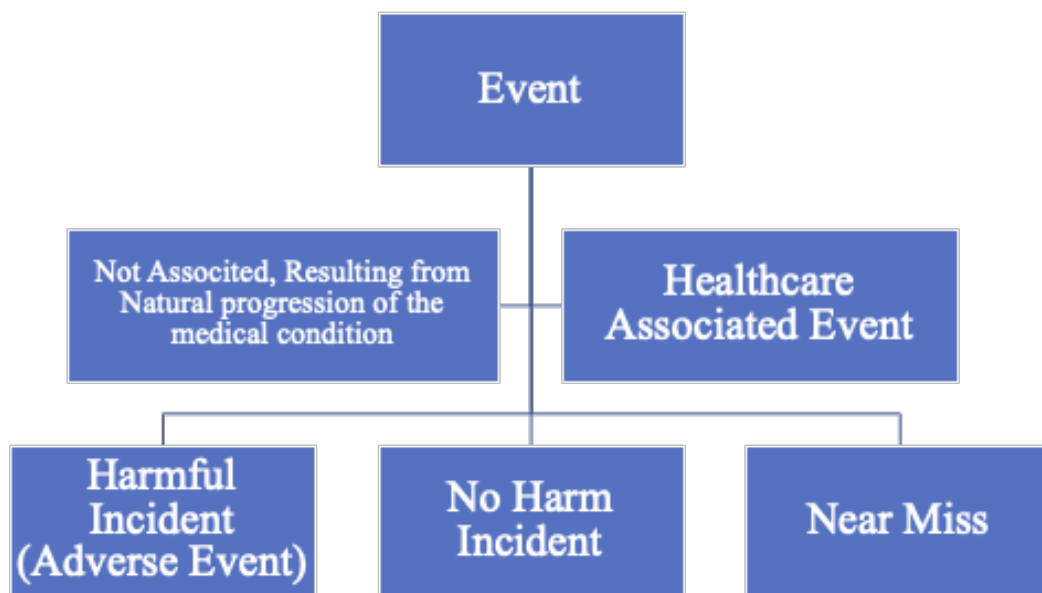
Although major studies and initiative were taken in the 20th century regarding patients' safety, it was until the last two decades that this subject was highlighted; and this was in major due to the popular publication "To Err is Human ", a report of the Institute of Medicine that was published in 2000 and that is considered as the foundation of patients' safety movement (27). This report acknowledged medical errors can hurt patients' safety but also reinforces the necessity of a systematic model to assess and evaluate these incidents. This momentum also motivated the establishment of an international classification of patients' safety by the World Health Organization (28) (Appendix 3), with the goal to align definitions, terms, and standardize processes.

The publication also defined key terms like incidents and related concepts.

- Incident is any unplanned and unintended circumstance which can harm the patient. It can be any reportable circumstance, near miss, no harm incident or adverse event (harmful incident)
- Reportable Circumstance : A situation where no harm was caused to the patient, but there is a potential that it can harm another patient.
- Harmful Incident (Adverse Event) : An incident that caused harm to the patient
- No harm incident : An incident that didn't cause any harm to the patient. For example, a certain medication was given to the wrong patient but without any effect.
- Near miss : An incident that didn't cause any harm to the patient but could have.

Besides this organisational efforts to understand the occurrence of healthcare associated adverse events, the most important step for modern patient safety was the implementation of checklists. The initial checklist concept was imported from aviation with the goal of identifying key tasks that can be prone to human error and prevent it.

A great example of the impact of introducing checklists was done in Michigan's Intensive care units, where the establishment of a checklist helped reduce and sustain more than 66% of catheter-related bloodstream infections (44). The checklists were early integrated in Neurosurgical and Anesthesia care, and this was consolidated by the WHO publication in 2009 of the Surgical Safety Checklist (Annex 1), which proved effective. The first prospective study from more than 7688 patients showed a significant decrease in both death (1.5% to 0.8%) and complications (11% to 7%) after the implementation of the intervention (45).



Following the interesting results in other operating sites, the neurosurgical checklists started being implemented as described in the table (Annex 4). One of the great series we found while reviewing literature, is the one by K.Lyons in Mayo Clinic, department of Neurological Surgery for more than 8 years (46). Reports also emphasized that Operating Rooms and Neurological Surgery teams are complicated entities demanding coordinated cooperation by interdisciplinary members. To enhance teams performance, open and 2-way communication is crucial. Neily et al. showed in a multicentre, pre and post intervention study, the importance of briefing, debriefing and coaching sessions on improved communication within OR teams. Safety can also be improved by supporting and implementing sub-specialities and investing in excellence centers and also diminishing hospital and surgical volume, by promoting regionalization.

As for the Neurosurgical specificities, Wong et al. (47) succeeded in identifying the most common adverse events, aside from patient condition, in neurological surgery and disaggregated them by contributing factors (Annex 5)

Finally, it is just by the cumulative efforts in building anesthesia and surgical trainees, implementing checklists, investing in teamwork and open communication, and measuring the impact of the interventions that we can achieve better patient safety in neurological surgical care (48).

III. Cranial Surgery procedures and patients' positioning

A - General Consideration for positioning

Positioning is an important step in perioperative care, and especially in neurosurgery, as it is characterized by a wide variety of pathologies requiring adequate patients' positioning. Correct positioning and close attention to details can help prevent any adverse events (VAE, Musculoskeletal and nerve damages). Thus, patient safety, optimal surgical and anesthetist access, and surgical comfort should all be considered while preparing a patient for a surgery. This should be addressed in preoperative evaluation and is the responsibility of both the surgeon and the anesthetist (49). The intended positions should also support neuroanesthesia objectives such as lowering intracranial pressure (ICP), reducing brain retraction, providing a clear and bloodless surgical view, and avoiding venous obstruction. The best positioning should allow optimal access to the lesion, and also allow venous drainage (50). It is also important to emphasize that neurosurgical patients are specific and that ACLS protocols cannot always be applied during cardiac arrest. Due to patient positioning and surgical exposure, it is frequently impractical to proceed with ACLS algorithms right away. Thus, it is important to fully understand the impact of positioning on patients and the management of any cardiac asystole or cardiac adverse event necessitating a CPR.

Positioning a patient requires starting first with the body, then the head fixation, this process often occurs after the induction of anesthesia and the placement of venous and arterial catheters. It is also important to pay attention to the the head, neck, body axis, as sustained hyperflexion, hyperextension, and rotation can have severe outcome with the brainstem and cervical stem ischemia.

Finally, It is vital to pay attention to the vital signs and keep monitoring the patient when repositioning a patient and while adapting their body and head position, in this period called blackout, a minimal pulse oximetry should be maintained. To strengthen this process, a repositioning checklist can be recommended (34)

Table V: Repositioning Checklist

A	Airway	Endotracheal Tube	ETT in correct position
B	Breathing	Observation Auscultation and Monitoring	Pulmonary compliance, SpO2, Canograph trace
C	Circulation	Observation	HR, BP, ECG
D	Disability	Eyes	Tapped, Closed and Protected
E	Exposure	All cables, catheter and access	Checked , Maintain access for

B - Historical Background

Victor Horsley, was the first neurosurgeon to describe the necessity of having separate head immobilisation (52). Harvey Cushing also described the use of pillows to elevate the head, then revolutionized the world by developing the horseshoe rest that is still in use in modern operating rooms. Other Neurosurgeons like Charles Frazier and Fedor Krause emphasised on the advantage that might provide changing the positioning during surgical care.



Figure 12: Modern Mayfield Horseshoe

Over the past century, a lot of teams proposed innovative positions with trial and error while keeping patients' safety and the quality of surgical care as priority. One of the most used instruments in neurosurgical care are headrest and pin fixation skull clamps, these inventions were the product of the famous Frank Mayfield and George Kees who developed this to allow optimal fixation of the head while performing surgery. As for the operating tables, the first descriptions were done when lithotomy was prevalent in Europe, where basic wood operating tables would position the back elevation and allow a "Lithotomy Position", also known as Gynecological position.



Figure 13: An Operating Table from 19th Century

In modern days, Operating tables can be either mobile or stationary, and offer multitude of possibilities for the operating team such as (Height adjustment, tilting, and adjustable parts allowing for maximum modularity; and new advancement allowed for the creation of radiolucent tables that proved revolutionary in some neurovascular procedures (53).

C - Craniotomies :

A craniotomy is a surgical operation that involves temporarily removing a portion of the skull to expose the brain and execute an intracranial surgery (54). The nomenclature of craniotomy is determined by the name off the skull bone opened (eg.: Frontal craniotomy for opening the frontal bone), the size of the incision (eg.:burr hole craniotomy), or the technique used (eg.: stereotactic craniotomy). We can describe 6 basic types of Craniotomies :

A - Anterior Parasagittal
B - Fronto Sphenotemporal
C - Sub-Temporal

D - Lateral Suboccipital
E - Midline Suboccipital
F - Post Parasagittal

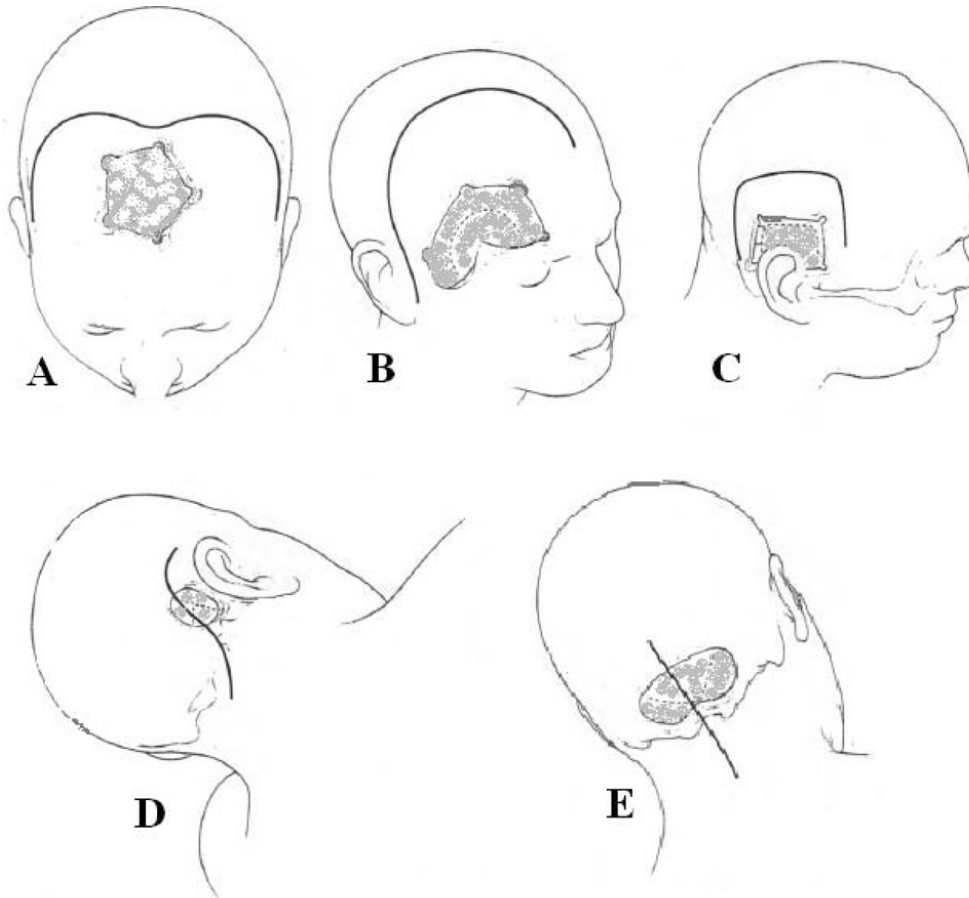


Figure 14: Type of Craniotomies

D - Body positioning for Craniotomies :

Body positioning can have several implications on physiological parameters of ventilation, cardiovascular functions, and the central nervous system. They have been summarized by Rozet and Al. (55) in Annex 4. Positioning can also have immediate and short term complications (Peripheral nerve injuries, ocular injuries, and pressure sores); this is why it is important to understand every implication of the main position in neurological surgery.

1 - Supine Position (Dorsal Decubitus):

Supine position is the most used position in neurosurgery. This position is considered as a gold standard position for cranial procedures but also carotid endarterectomies. Requiring minimal equipment, this position is also safe as no blackout moments are required because the patient can be placed before induction. We also describe 3 sub-types including the horizontal position (Figure15), Contoured Position and Reverse trendelenburg.

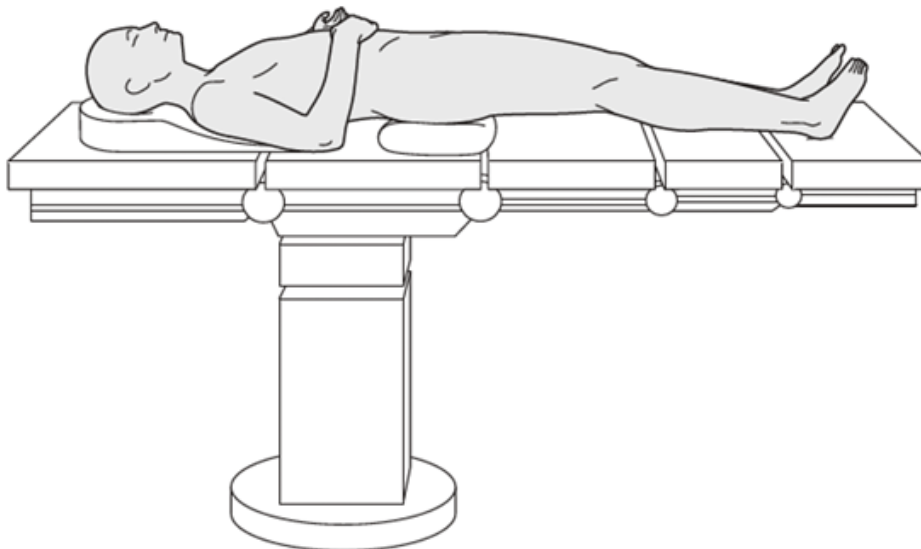


Figure 15: Supine position (Horizontal subtype)

The contoured position allows optimal physiological positioning of the hip, and the lumbar spine; and also improves venous, lymphatic and CSF circulation. From a circulation point of view, this position offers optimal cardiac output and stroke volume. Gravity has a great impact on ventilation. In standing position, the pulmonary base includes compliant alveoli, the apex, on the other hand, ventilates less efficiently and J. B. West and al. described this concept in experimental models (56). S. Manikandan and al. proved that percentage changes of PaO₂ seen in lateral and prone groups were significantly different from that in supine group and a significant increase in supine patients PaCO₂ levels after induction, due to increased alveolar dead space (57)

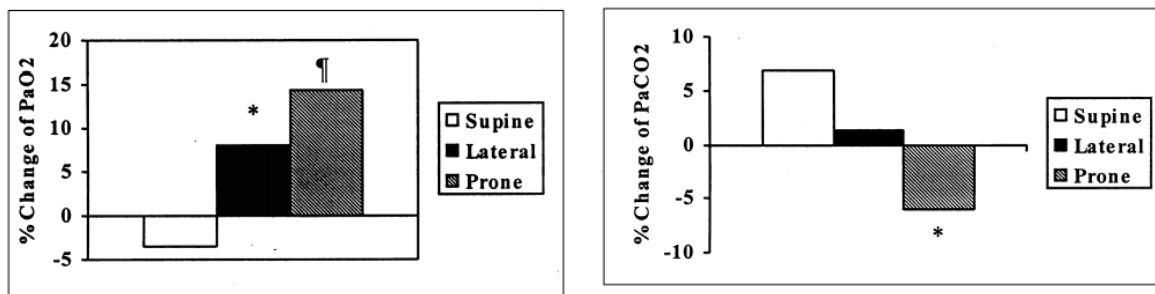


Figure 16: Changes of PaO₂ and PaCO₂ after Induction depending on position (Supine,Lateral,Prone) adapted from (57)

2 - Prone Position :

The prone position is commonly used to access the suboccipital region, but has a lot of interest in spinal surgery. Compared to the supine position, the prone requires extra attention to the re-positioning, as the patient is induced in supine position then turned; the ventral decubitus also causes issues related to access to the ETT. This position offers some interesting advantages for ventilation as it decreases atelectasis of the dorsal zones, and the ventilation/perfusion mismatch compared to supine, and also decreases VAE risk compared to sitting position. In this position, the increased intra-abdominal pressure causes a decrease in Venous return, and decreased cardiac output that is compensated through an increase in heart rate (58). Modified positions like the Concorde Position and the Genupectoral, offer different approaches and benefits.

The Concorde position (Figure18) is often used to approach the occipital trans tentorial and supracerebellar infratentorial area (59), the reverse trendelenburg increases venous return.

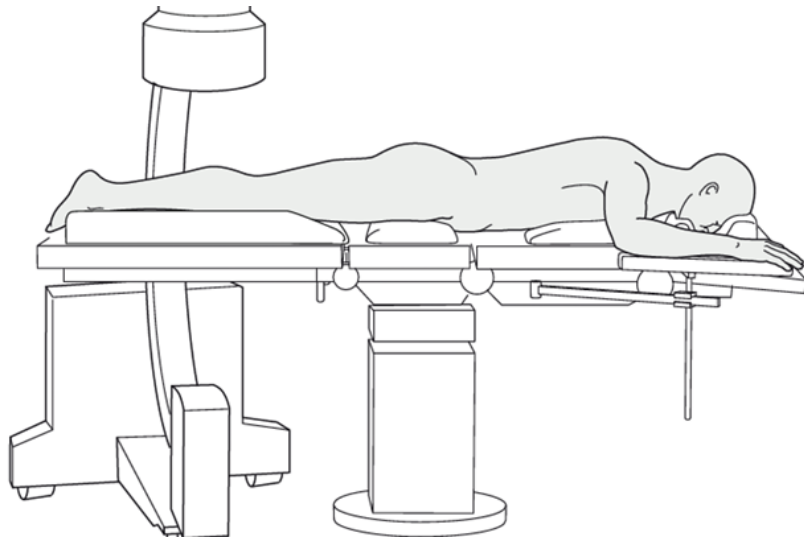


Figure 17: Prone position

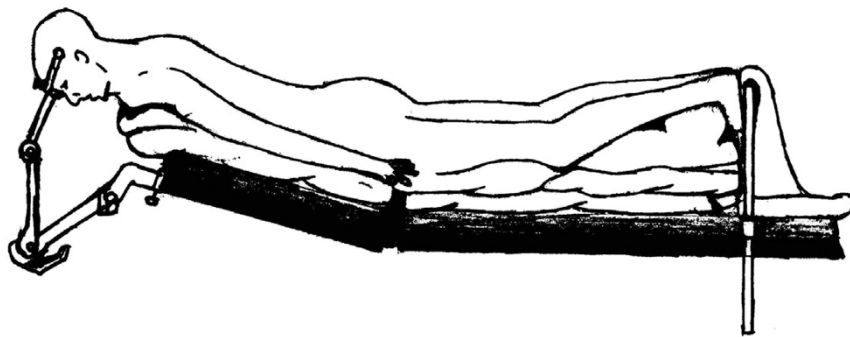


Figure 18: Concorde position

3 - Lateral Position :

The lateral position is commonly used to access the temporal lobe, posterior fossa and the skull base. The lateral position has similar ventilation/perfusion mismatch as the supine one, but the impact on the oxygenation is minimal (Manikandan) . Hemodynamic parameters are also not changed, with only a minimal decrease in MAP, caused by the increase in systemic vascular resistance. Risks of this position include the vascular compromise and the brachial plexus injury thus, special attention should be given to the position of the arms. The Park bench position is a modification of the lateral position allowing better access to the posterior fossa.

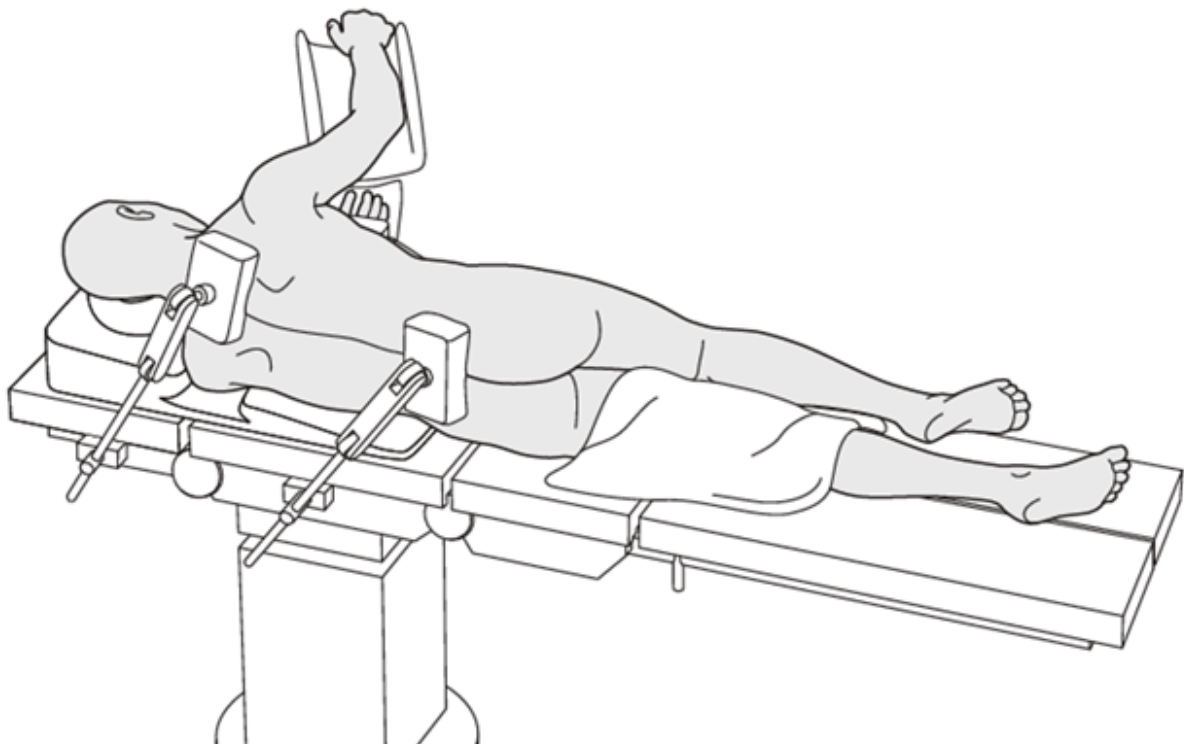


Figure 19: Lateral Position

4 - Sitting position

The Sitting position is used to access the posterior fossa. The sitting position offers improved ventilation compared to the supine as the diaphragmatic movements are improved (60). The effect of gravity and the venous pooling in the lower limbs lowers the CO and the MAP, the compensation is made and heart rate is increased. This lower extremities venous pooling can also be fixed by using compression socks. This position remains controversial (61) with the multiple risks associated with it (hemodynamic, VAE, bradycardia, pneumocephalus (62)

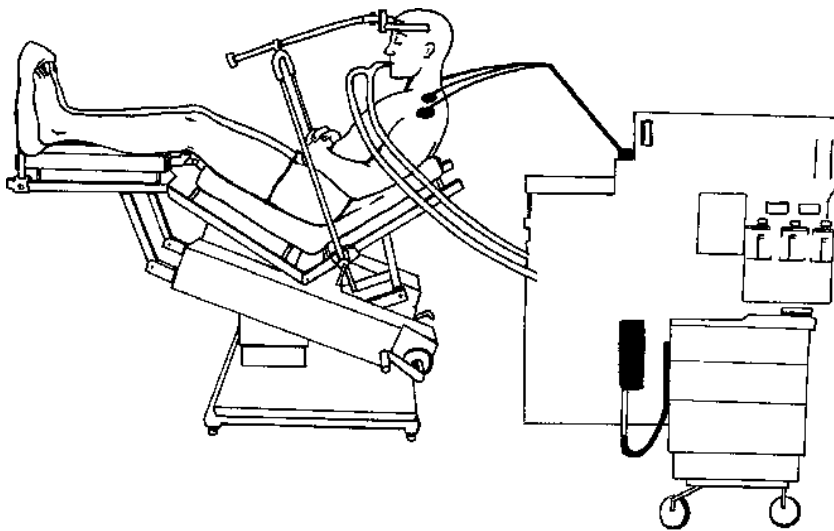


Figure 20: Sitting Position

E - Head positioning:

Head positioning allows enhanced surgical access to the area. However, special attention should be given to head and neck positioning as adverse events can be associated with this procedure. Modification, even minimal rotation, flexion, extension of the head cause changes to the blood flow in carotid and vertebral arteries (63). If this is sustained for hours, this might lead to an ischemia that can be severe with quadriplegia, and even quadriplegia.

IV. Pathophysiology and Management of frequent Cardiac Complications in Perioperative Neurosurgery

There is no consensus about the definition of cardiac complications in perioperative neurosurgery. For the Purpose of our study we included “Cardiac Arrest” “Asystole” “Ventricular Fibrillation” “Pulseless Electrical Activity” and “Severe Bradycardia” and “Severe Hypotension”. All these events might be an alarm for an upcoming cardiac arrest, a dreadful event, related with a huge morbidity and mortality.

The Term perioperative is also not well defined as it may include all events during preoperative, intraoperative, and postoperative, for this study we will concentrate on intraoperative adverse events. Physiopathology of Cardiac arrest will be discussed separately in Chapter IV.

A - Intraoperative hypotension:

Intraoperative hypotension (IOH) is a common intraoperative complication, an adverse event associated with multiple postoperative outcomes (64), such as acute kidney injury, and myocardial injury (65), postoperative stroke (66). It's also important to note that studies reporting IOH and its association with adverse events used different definitions, as some of them defined the IOH as a decrease in Blood pressure below an absolute number, others used thresholds related to the patients' baseline blood pressure. However the recent study from 2020 showed that the association between IOH and morbidity and mortality was constant for all definitions and thresholds (67).

The duration of hypotension and the length of time is also correlated with 30-day mortality and cardiovascular events (68). IOH is also relevant as several neurosurgical interventions proceeded in a prone position.

Table VI: Summary of main IOH definition

Author	Type of Definition	Values
Walsh et al. (65)	Absolute threshold	MAP < 55 mmHg
Monk et al. (69)	Absolute threshold	MAP < 50 mmHg (5min) Systolic Blood Pressure < 70 mmHg
Klasen et al. (70)	Patients' Baseline	A decrease of more than 30% of the baseline blood pressure within 10 min of the Anesthesia

Taffé et al. estimated an incidence of hypotension around 1 to 12% of non-cardiac surgeries and confirmed its association with postoperative complication and death (71), a more recent study also showed that a sustained MAP between 50 and 80 mmHg, was associated with 30-day mortality (72) (69). This mortality can be explained by the poor circulation and the hypoperfusion, causing injuries

to the kidneys, the heart and other organs. Walsh et al. (65) also confirmed the association between the duration of hypotension and the myocardial and kidney acute injuries.

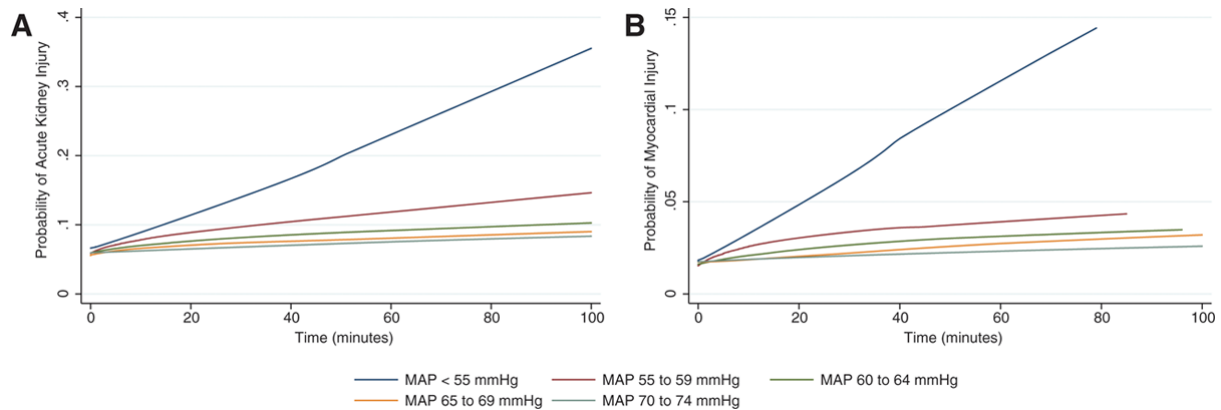


Figure 21(65): Predicted risk of (A) acute kidney injury and (B) myocardial injury for each minute the mean arterial pressure (MAP) is <55 mmHg, between 55 and 59 mmHg, between 60 and 64 mmHg, between 65 and 69 mmHg, and between 70 and 74 mmHg during noncardiac surgery. The risk for time in each blood pressure strata is adjusted for time in all other blood pressure strata.

Blood pressure is dynamic, continuously regulated on the short term by the autonomous nervous system as a balance between the sympathetic and parasympathetic nervous system.

Arterial Blood Pressure = Cardiac Output x Systemic Vascular Resistance

With :

- Cardiac output = Stroke Volume x Heart Rate
- Systemic Vascular Resistance = $(8 \times L \times n) / (\pi \times r^4)$

- L : Length of the vessel
- n : Viscosity
- r : Arteriolar caliber

We can understand that any condition or molecule that can decrease the stroke volume, heart rate or dilate the caliber of arterioles will result in a hypotension. Therefore, We categorize the occurrence and the incidence of IOH in 5 points :

a - Patients' related causes : A long term use of calcium antagonists, angiotensin-converting enzyme inhibitors, beta-blockers, and Renin-Angiotensin-Aldosterone antagonists was associated with intraoperative hypertension(73). However, beta-blockers and calcium channel blockers shouldn't be discontinued on the day of surgery (74)

b - Anesthesia related causes, as anesthesia can have 2 main results; with a Direct effect on Peripheral circulation; or an Indirect effect, explained by the central action of anesthesia, and the decrease of sympathetic system tonus.

c - Surgery or Position related causes : IOH incidence is correlated with the length of the surgery and we can identify visceral surgeries as the main providers of IOH (75). Positioning can also cause hypotension, as this is widely described in sitting position.

d - Ventilation related causes : Mechanical ventilation causes diverse physiological effects including decreasing cardiac output, increases right and left ventricular afterload; which can lead to hypotension (76).

As we discussed IOH can have severe adverse events that can potentially cause myocardial, kidney injury or other severe complications. The objective for anesthetists is then to maintain a MAP > 65mmHg or within 20% of patients' baseline measures, especially for patients with hypertension, where higher MAP targets are needed (77). However, up to this date there is no consensus about the exact therapeutic approach for IOH (78), and further randomized controlled trials are needed to strengthen our understanding of IOH management. In general anesthesia, hypotension can occur during all the phases of operation. But the management of this condition should be adapted to the cause and the etiology.

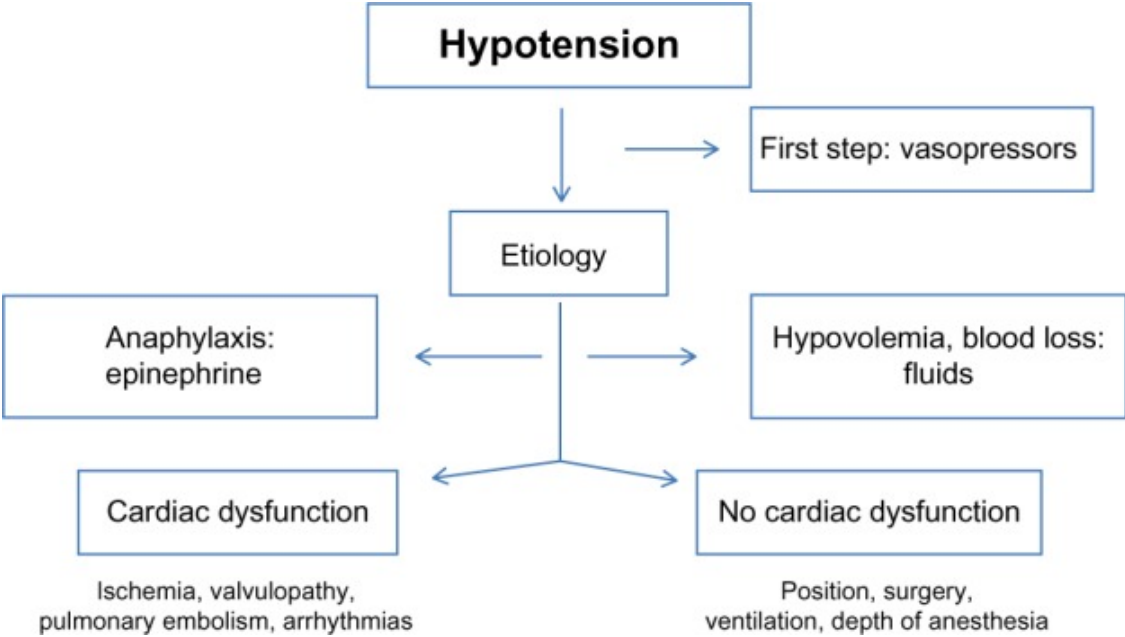


Figure 22: Main treatment of hypotension according to main etiologies (79)

The first way to decrease the risk of IOH, is to control the depth of anesthesia. Bispectral Index Monitoring can be a valuable tool to assess the intensity and depth of anesthesia. A study by Petsiti et al. confirmed that deep hypnotic time - time when bispectral index < 40 - is a factor associated with severe surgical outcome (80). To minimize the effect of anesthesia on depth of hypnosis, it is important to adjust doses, techniques, and anesthetic agents used during the induction, maintenance phases. It is also mandatory to titrate anesthesia agents in elderly and patients with septic shock. Fluid administration is also an important pillar in IOH management. In fluid-responsive patients, administration of IV fluids will help increase blood pressure, by increasing stroke volume and cardiac output. Ultrasound of the Inferior Vena Cava (IVC) is a great tool to assess the intravascular volume in anesthetized patients. A randomized controlled trial by Myrberg et al. , also shared some insightful findings on preoperative fluid bolus, as it was correlated to a decrease in the incidence of BP drops in rapid sequence induction (81). In a fluid responsive patient, the trendelenburg position can increase BP by mobilizing blood volume in lower extremities aided by gravity (82). Main parental vasopressors agents include Epinephrine, Norepinephrine, Ephedrine, Phenylephrine. Epinephrine is the gold standard treatment for hypotension related to anaphylaxis and cardiac arrest but can also be used to treat sudden hypotension. Ephedrine is often used when hypotension is associated with bradycardia, ephedrine action on beta receptors causes direct augmentation of heart rate. Generally, the choice of medication should be adapted by the anesthetist depending on patients' condition and the type of surgery, and the cause of hypotension.

Table VII: Main Vasopressors Agents and Initial Doses

Drug	Initial Dose
Epinephrine	0,1 - 1 mg
Norepinephrine	0,1 - 0,4 ug/kg/minute
Ephedrine	3 - 6 mg
Phenylephrine	50 - 100 ug

B - Cardiac Arrhythmias:

We define arrhythmias as a different rythme from the sinus normal one. The anomalies can concern the frequency, the intensity and the contractions. We can simplify the Electrocardiography into 2 branches :

- Shockable Rhythms : Ventricular Tachycardia and Ventricular Fibrillation
- Non-Shockable Rhythms : Pulseless Electrical Activity and Asystole

Cardiac arrhythmias are commonly encountered during perioperative period , and are one of the most dreadful events. Cardiac arrhythmias can be caused by drugs administration (premedication, analgesic, vasopressors..), procedure and surgical stimuli, position, and patients history of disease and/or pathology (Electrolytes, Cardiac disease). The mechanisms for cardiac arrhythmias can be divided into impulse formation problems and impulse conduction problems. Impulse formation problems may include altered normal automaticity, abnormal automaticity, delayed afterdepolarization, early depolarization; and impulse conduction disorder includes anatomic and functional reentry.

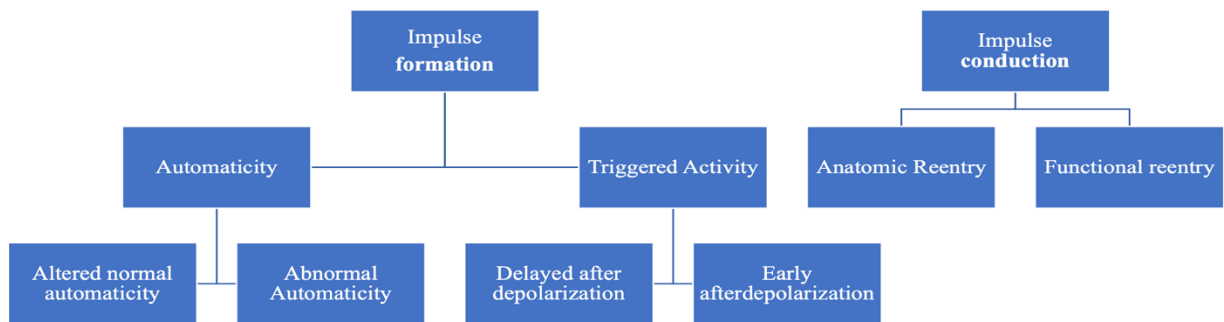


Figure 23: Simplified Mechanisms of Cardiac Arrhythmias

C - Pathophysiology :

Automaticity disorders : Automaticity is defined as the capability to generate an action potential (AP). Cells in the sino-atrial node have spontaneous firing capacity and are considered as pacemaker cells, however other cells like Purkinje system cells, the Atrioventricular node, also possess this propriety (83). In normal circumstances, the Sino-atrial node is “The Maestro” maintaining its fast rate of fire compared to the other cells, thus we call a normal hearth rhyme, the sinus rhythm.

Triggered Activity occurs when abnormal action potentials are triggered by a previous action potential, it can cause atrial or ventricular tachycardia. Triggered activity is defined by impulse initiation caused by afterdepolarizations (84) (membrane potential oscillations that occur during or immediately following a preceding AP). These oscillations can reach a threshold potential initiating the depolarization of the cell and thus trigger a propagated response.

- Early afterdepolarizations appear at the end of the plateau of the action potential . The triggered activities induced by these early post-depolarizations appear for low frequencies.

- Delayed afterdepolarizations appear after repolarization and are favored by the increase in the intracellular concentration of calcium and circulating catecholamines. Certain ventricular tachycardias are due to triggered activities induced by these late post-depolarizations. They are also observed in cases of digitalis poisoning.

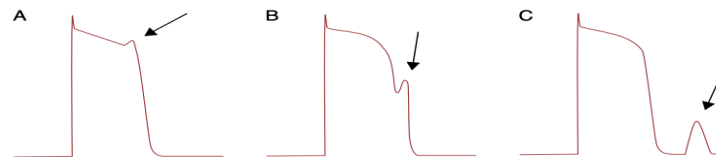
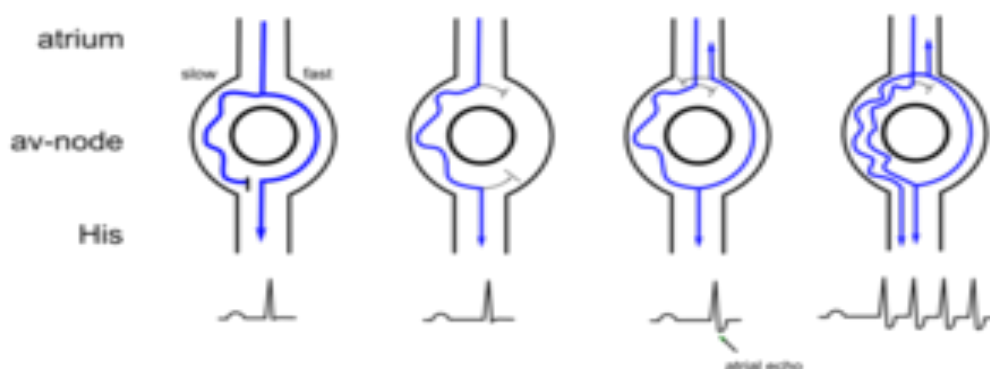


Figure 24: Representation of triggered activity; A: phase 2 early after depolarization ,B: phase 3 early after depolarization, C: delayed after depolarization

Reentry disorders phenomenon imply the presence of two possible conduction paths for the electrical impulse. A unidirectional block on one of the tracks is the initiator of the reentry; the impulse then progresses along the other path, in which the conduction must be slow enough that it can then proceed in the retrograde direction to the first conduction path, which has become permeable. The circuit is thus initiated and the impulse circulates in a circular fashion between the two conduction paths. Most childhood tachycardias are reentry: reciprocal junctional tachycardias and flutter obey this mechanism.



D - Management

Pulseless Ventricular tachycardia and Ventricular Fibrillation should be quickly detected by the anesthetist on the ECG Cardioscope (Fig X) and propose the adequate protocols. The immediate task is to correct any reversible etiology that can include (Hypotension, Hypoxemia, Acidosis and other electrolyte imbalances, Surgical stimulation, light anesthesia) then to propose rapid defibrillation. Concerning pharmacological interventions, AHA recommends the use of Amiodarone or Lidocaine in VT/VF resistant to defibrillation (85). These recommendations are based on the 1999 Arrest Study that showed the benefits of Amiodarone in the short term outcome of ROSC. Amiodarone should be given as 300mg Bolus, then 150 mg.

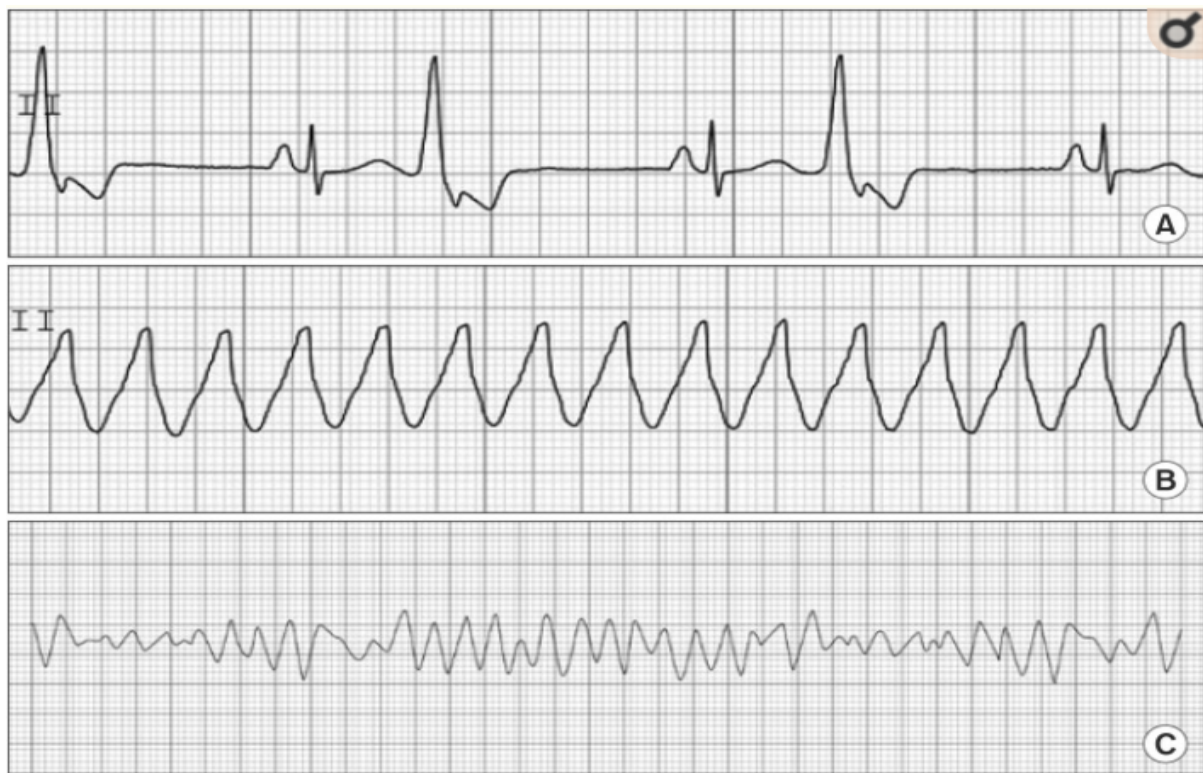
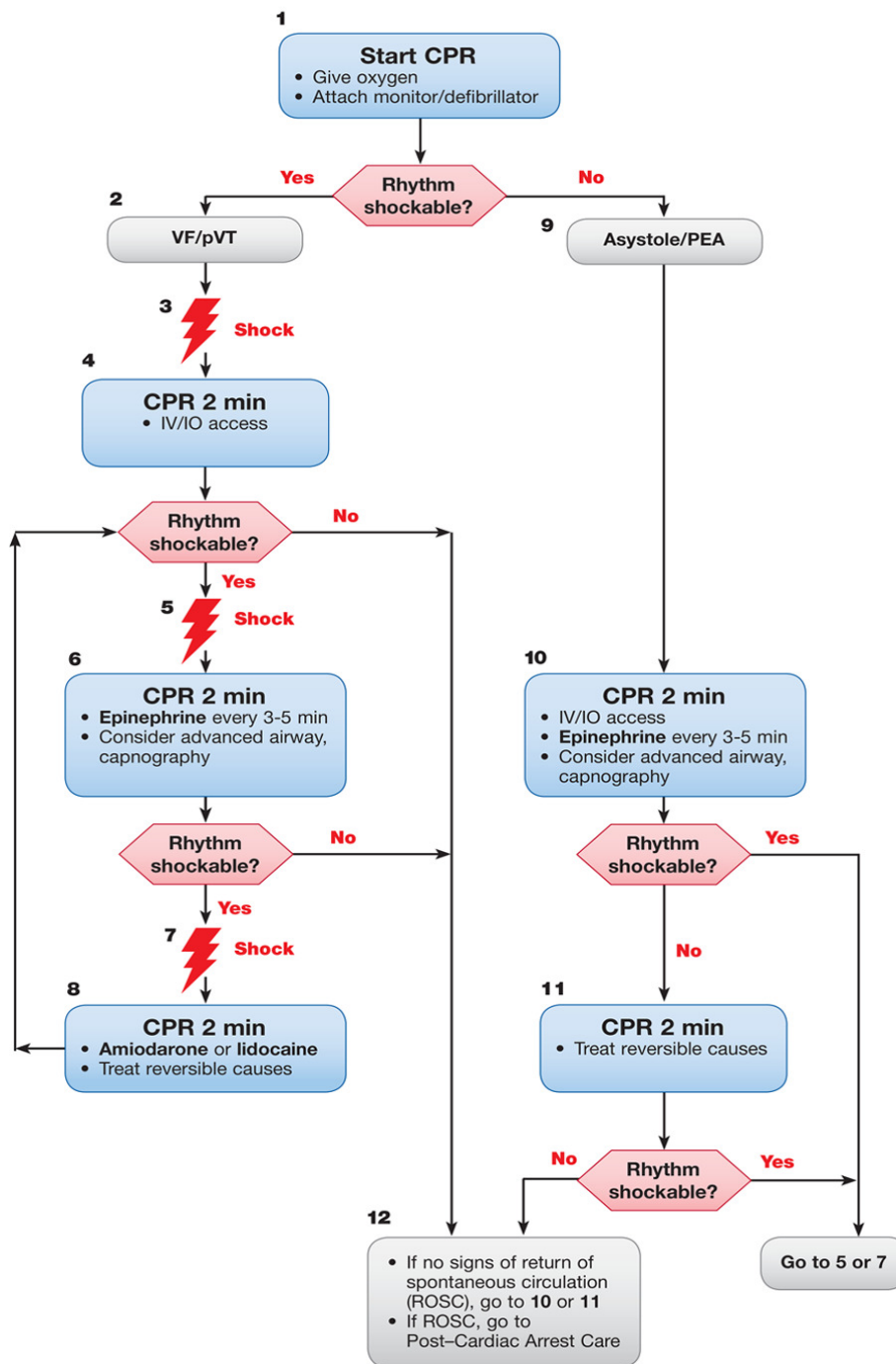


Figure 25: Difference between (PVC) (A), Ventricular Tachycardia (B) and Ventricular Fibrillation in ECG (C) (86)



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Figure 26: AHA Guidelines for management of VF/pVT

CPR Quality
<ul style="list-style-type: none"> • Push hard (at least 2 inches [5 cm]) and fast (100-120/min) and allow complete chest recoil. • Minimize interruptions in compressions. • Avoid excessive ventilation. • Change compressor every 2 minutes, or sooner if fatigued. • If no advanced airway, 30:2 compression-ventilation ratio. • Quantitative waveform capnography <ul style="list-style-type: none"> – If PETCO₂ <10 mm Hg, attempt to improve CPR quality. • Intra-arterial pressure <ul style="list-style-type: none"> – If relaxation phase (diastolic) pressure <20 mm Hg, attempt to improve CPR quality.
Shock Energy for Defibrillation
<ul style="list-style-type: none"> • Biphasic: Manufacturer recommendation (eg, initial dose of 120-200 J); if unknown, use maximum available. Second and subsequent doses should be equivalent, and higher doses may be considered. • Monophasic: 360 J
Drug Therapy
<ul style="list-style-type: none"> • Epinephrine IV/IO dose: 1 mg every 3-5 minutes • Amiodarone IV/IO dose: First dose: 300 mg bolus. Second dose: 150 mg. –OR– • Lidocaine IV/IO dose: First dose: 1-1.5 mg/kg. Second dose: 0.5-0.75 mg/kg.
Advanced Airway
<ul style="list-style-type: none"> • Endotracheal intubation or supraglottic advanced airway • Waveform capnography or capnometry to confirm and monitor ET tube placement • Once advanced airway in place, give 1 breath every 6 seconds (10 breaths/min) with continuous chest compressions
Return of Spontaneous Circulation (ROSC)
<ul style="list-style-type: none"> • Pulse and blood pressure • Abrupt sustained increase in PETCO₂ (typically ≥40 mm Hg) • Spontaneous arterial pressure waves with intra-arterial monitoring
Reversible Causes
<ul style="list-style-type: none"> • Hypovolemia • Hypoxia • Hydrogen ion (acidosis) • Hypo-/hyperkalemia • Hypothermia • Tension pneumothorax • Tamponade, cardiac • Toxins • Thrombosis, pulmonary • Thrombosis, coronary

V. Generalities about Cardiac Arrest

A. History

The interest for Cardiac Arrest Grew only after the establishment of Anesthesia in 1842 (87); but the first descriptions Cardiac Arrest and Sudden death were shared by Hippocrates "Those who are subject to frequent and severe fainting attacks without obvious cause die suddenly." (88)

In 1732, The world witnessed the first reported expired air resuscitation, executed by the Scottish surgeon William Tossach (89) . Looking back for earlier references of cardiopulmonary resuscitation, we can find rare mentions about the Prophet Elisha (اليسع) reviving the Shunamite child (87) “ Kings 4: 32 When Elisha came into the house, he saw the child lying dead on his bed [...] Then he went up and lay on the child, putting his mouth on his mouth, his eyes on his eyes, and his hands on his hands. And as he stretched himself upon him, the flesh of the child became warm”.

Nowadays, If it's normal to consider cardiac arrest as an acute event necessitating the intervention of medical personnel or trained community members, it wasn't the case in the past. Until the 18th century, the practice of Mouth-to-Mouth resuscitation,also known as expired air ventilation , was exclusively done by midwives for newborn, and watermen for the drowned. During the 18th century, Electric shock was described to correct a heart arrest ; and beginning in the late 1800s, heart surgery pioneer Claude Beck performed the first successful defibrillation in 1947 on a 14-year-old boy experiencing ventricular fibrillation during one of his surgeries. In 1960, Kouwenhoven (90) developed the basics of an external cardiac massage and set the basis of an ongoing evolution leading to the 2020 AHA and ILCOR updated guidelines.



Figure 27: Journal showcasing an early ancestor of the defibrillator in 1933

Since the International Recommendations of the American Heart association concerning resuscitation and cardiac arrest management in 1992 (91), the diagnosis was mainly based on loss of consciousness, non-reactivity and absence of Carotidian or femoral pulse. Today, the 2020 AHA and the on the International Liaison Committee on Resuscitation (ILCOR) 2020 Consensus on Science and Treatment Recommendations for ALS and the European Resuscitation Council guidelines insist on the early diagnosis, alert, early and quality CPR for unresponsive patients and with absent or abnormal breathing (agonal breathing) (92).

B. Definitions

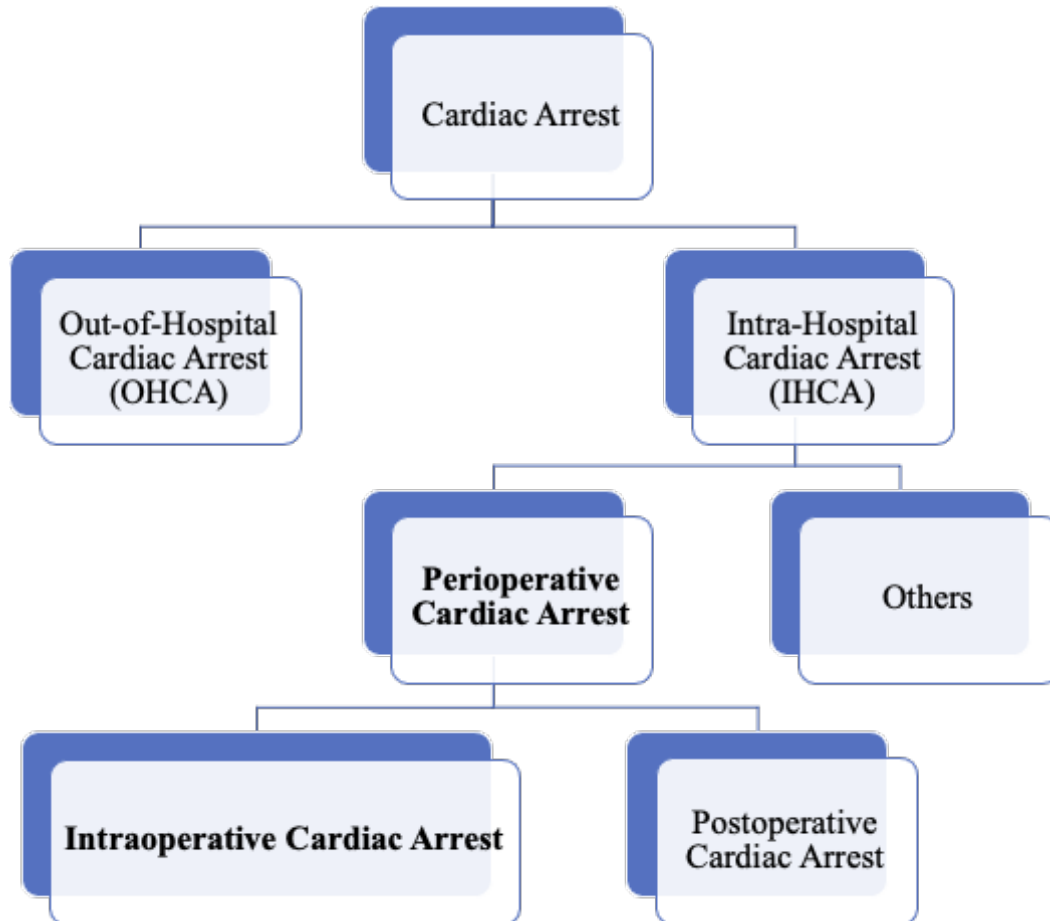


Figure 28: Simplified Cardiac Arrest Diagram

Defining Cardiac Arrest

Cardiac arrest (CA) is defined as “the cessation of the mechanical activity of the heart and is confirmed by the absence of signs of circulation” (93), and the immediate treatment is often based on chest compressions with or without ventilations, in hope to restore a ROSC. The management of CA is regulated by the International Liaison Committee on Resuscitation. The importance of understanding and applying fast and efficient CPR is to sustain a high survival rate, as survival rate is decreasing by 10% every minute without CPR (94).



Figure 29: Survival Rate (Percentage) by Elapsed Time (Minutes)

The Chain of Survival

The Chain of survival is a series of interdependent actions that, if executed properly, will decrease the CA mortality. The concept was first described by Cummins et Al (95), and included early access, early CPR, early defibrillation, and early advanced care; it has since then evolved throughout the years and the last version was updated in 2020 by the AHA (96).

The 2020 Chain of Survival includes Recovery as a new link to all chains (OHCA,IHCA, Pediatric) in addition to the traditional early recognition and prevention, activation of emergency response, quality CPR, defibrillation, post-cardiac arrest care.



Figure 30: The 2020 American Heart Association Chains of Survival for Adults' OHCA and IHCA.

Data also showed that survival from an adult in-hospital cardiac arrest was superior after a first documented shockable rhythm of VT or VF compared with a first documented nonshockable rhythm of PEA or asystole, the same study that analyzed the US National Registry of Cardiopulmonary Resuscitation, also showed that the most common IHCA rythmes are Asystole and PEA (73).

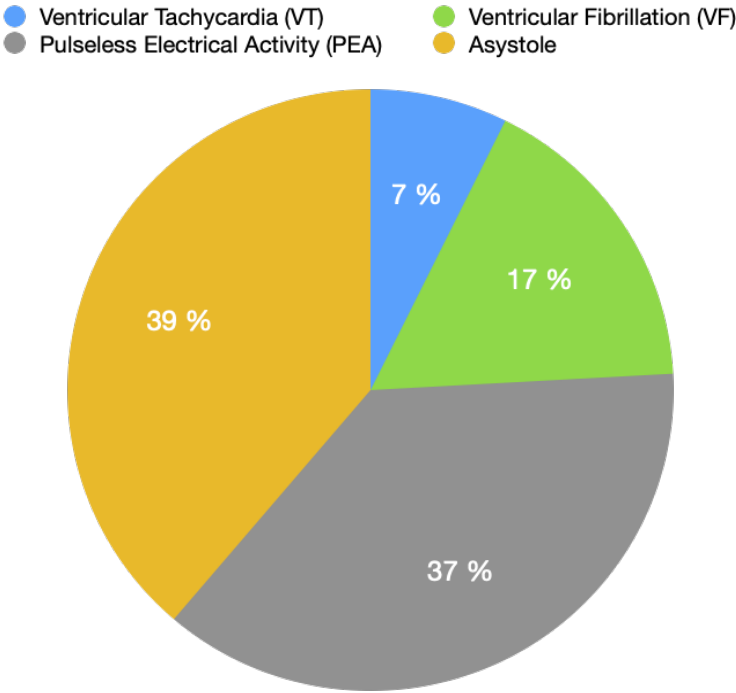


Figure 31: Distribution of IHCA Rythmes (27)

C. Diagnosis

Clinical Diagnosis of IHCA is based on the ability of the healthcare delivery teams to detect unconsciousness, agonal breathing, and paradoxical respiration, and seizure-like events. Previously, the absence of a detectable pulse was a criterion for detecting cardiac arrest, but it was very challenging for

professionals, specialists and also laypeople to accurately identify peripheral pulses in stressful circumstances. Unresponsiveness and irregular breathing clearly overlap with other potentially life-threatening medical emergencies, but they are sensitive for diagnosing the CA. The danger of initiating CPR in an unresponsive individual with absent or irregular breathing who is not in cardiac arrest is regarded to be considerably outweighed by the higher mortality associated with delayed CPR. This clinical approach is difficult in case of an Intraoperative cardiac arrest, as unconsciousness is irrelevant in case of a general anesthesia; but palpating femoral or carotid pulse can help in specific situations when monitoring is not available. In a highly monitored setting it is easy to detect and assess any perturbation to Blood pressure and other parameters, including electrocardiogram, etCO₂ and pulse saturation.

D. General Management

The modern history of Cardiac Arrest management started in 1960 with Kouwenhoven, and the international guidelines were updated every 5 years, leading to the last ILCOR and AHA recommendations in 2020.



Figure 32: First CPR Images - W Kouwenhoven, G Knickerbocker, 1961 Baltimore

Basic Life Support :

Every unconscious person, with absent or abnormal breathing should be considered as a cardiac arrest. Basic Life Support should be delivered starting with calling for emergency services, securing airways, and giving a 30 chest compression, 2 rescue breaths. Continuing Chest compression is important before the arrival of the Automated Electrical defibrillator. Fully automatic AEDs are designed to give an electrical shock without the need for further action from the rescuer (92). In case of a delivered shock, the Chest compression should be continued for 2 minutes, until the next pause for rythme analysis.

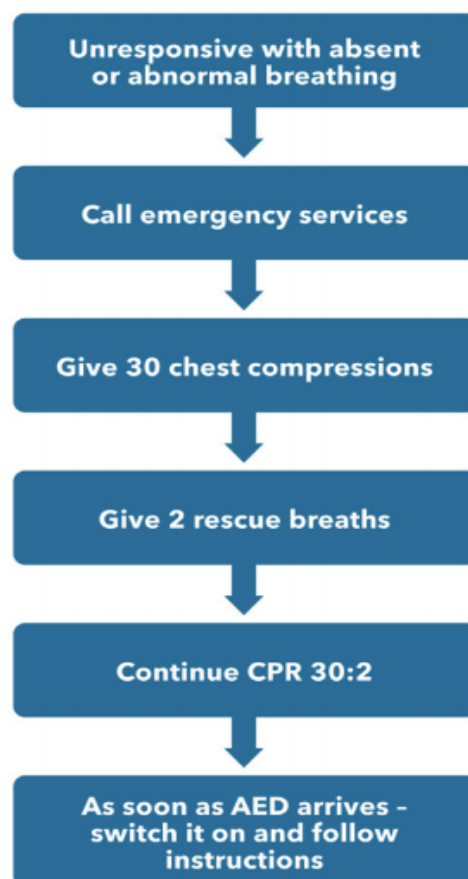


Figure 33: 2021 ILCOR Basic Life Support Algorithm

Advanced Cardiac Life Support :

Advanced Cardiac Life Support is the pillar of cardiopulmonary resuscitation, and it is an extension of BLS. ACLS was originally developed for OHCA, it was then deployed to In-Hospital settings with poor adaptation (97). However, new guidelines from ILCOR, AHA and other scientific organizations are including more and more insights about the management of CA in special circumstances including the In-Hospital, intraoperative phase and other scenarios (Catheterization Lab, dialysis...etc) (98) (99). Furthermore, with the COVID19 pandemic and the specificities in its management, special guidelines were developed for the infected patients (94). ACLS guidelines cover all procedures coming after BLS, but also airway management, drugs and inotropes usage, and treatment of associated arrhythmias.

ACLS is based on the same guiding principles of BLS, early detection, and quality chest compression and airway management. The 2021 ACLS guidelines insist also on the early use of Adrenaline if applicable (1mg every 3 minutes) (Non-shockable rhythms), or in shockable rhythms after 3 unsuccessful shocks .

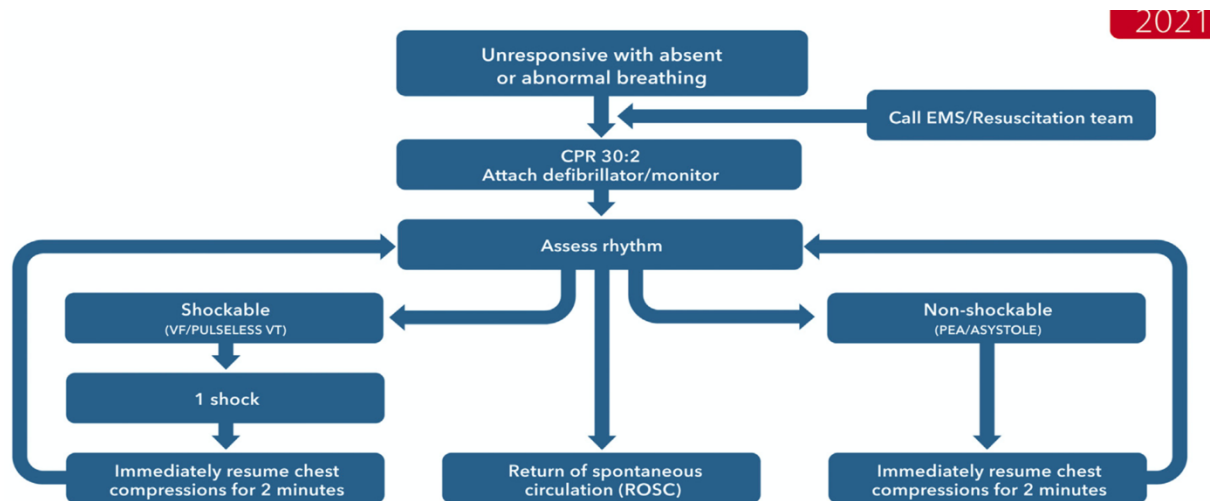


Figure 34: 2021 Advanced Life Support Algorithm

VI. Specificities of Intra-operative cardiac arrest

The first recommendations about the management and execution of CPR were initiated by the American Heart Association in 1974 (100). However the first official recommendation about the management of intrahospital cardiac arrest was shared in 1997, which explains the gap of knowledge between OHCA and IHCA. Intrahospital Cardiac arrest can be diagnosed both in monitored and unmonitored settings. As we are treating the intraoperative cardiac arrest, it is important to emphasize the particularity of IOCA, compared to other non-monitored cardiac arrests. The IOCA is a dramatic situation feared by any surgeon and anesthesiologist, although its occurrence is exceptional, its management is codified.

The management is always based on the same ground principles of OHCA, there are epidemiological, diagnosis, and management specificities that are dictated by the surgical setting and the anesthesia. Thus, it's also important to review the CA usual definitions that might not be always applicable to the perioperative setting. It is then important to emphasize on the physiological definition of a cardiac arrest as the cessation of cardiac mechanical activity as confirmed by the absence of signs of circulation (101) . Cardiac arrest in the operation room and procedural areas can be caused by a variety of reversible factors (5Ts and 5Hs). Thus, standard algorithms should be adapted to quickly assess and revert these causes.

Table VIII: Reversible Causes of CA

5 H	5 T
Hypoxemia Hypovolemia Hypo/Hyperkalemia Hypothermia Hydrogen Ion (Acidosis)	Toxins Tamponnade Tension Pneumothorax Thrombosis (Coronary) Thrombosis (Pulmonary)

A. Epidemiology

Today, patients' safety is an important pillar of patients' care, advances in therapeutics, management guidelines, and technological devices and close monitoring allowed to detect, and quickly treat cardiac arrest and peri arrest arrhythmias. However, the epidemiological studies showed that cardiac arrest is still a real risk to patients' safety during surgical procedures, but this risk is limited and highly dependable on the cause of the IOCA.

Table IX: Incidence of Intraoperative Cardiac Arrest in different studies

	N =	Cardiac Arrest Incidence
Goswami et al. (102)	362 767	0,072%
Kawashima et al. (103)	2 363 038	0,07%
Auroy et al. (104)	103 730	0,03%
Tiret et al. (105)	198 103	0,23%

Incidence of Cardiac Arrest can vary between 0,03% and 0,23%, and this is mainly attributed to the different definitions used, and different inclusion criteria for retrospective studies. A French study by Tiret et al (105) also demonstrated that Anesthesia induced cardiac arrest (0,06%) is less prevalent than Cardiac arrest not induced by Anesthesia (0,17%). These anesthesia induced cardiac arrest are also decreasing throughout the years with the increasing number of trained anesthesiologists, the improvement in patients' safety protocols and the wide usage of close monitoring (Pulse Oximetry and expired PCO₂ ...) (106). Other studies also showed that elective procedures are safer than emergency ones (107). Concerning anesthesia-induced cardiac arrest, American Society of Anesthesia (ASA) score can be a valuable tool to assess the risk of complications.

The United States National Anesthesia Clinical Outcomes Registry is a national database for anesthesia-related events allowing to study and analyse results and suggest means for improvement (108). In a 3 year study by Numally et al., this database analysis of more than 13 Million patients allowed for some interesting results that enhanced our understanding of Cardiac arrest in the perioperative phase. Cranial surgery accounts for 13,8% of all Cardiac arrests, coming 3rd after Abdominal and Intra-thoracic surgery. Cardiac arrest is less common in the periprocedural context than it is later in the hospital stay, and the majority of arrests concern ASA 3 - 4 and 5 patients. The Sex Ratio a higher risk for male is still needing more investigations.

Table X: Distribution of Cardiac Arrests by Surgery Type and region (111)

Region	Cardiac arrests	Cases count	Percent of cardiac arrests	Cardiac arrests as percent of total population	Cardiac arrests as percent of patients undergoing surgery in this region
Upper abdomen	405	328,350	15.75	12.00	0.12
Intrathoracic	377	108,530	14.66	4.00	0.35
Lower abdomen	342	362,647	13.30	13.30	0.09
Head	209	329,209	8.13	12.10	0.06
Neck	175	91,099	6.81	3.30	0.19
Unknown	154	405,566	5.99	14.90	0.04
Upper leg (except knee)	141	70,843	5.48	2.60	0.20
Radiological procedures	124	67,316	4.82	2.50	0.18
Perineum	115	203,282	4.47	7.40	0.06
Thorax (chest wall and shoulder girdle)	87	135,472	3.38	5.00	0.06
Knee and popliteal area	76	155,034	2.96	5.70	0.05
Spine and spinal cord	71	78,334	2.76	2.90	0.09
Forearm, wrist, and hand	67	104,644	2.61	3.80	0.06
Anesthesia care not required	66	42,810	2.57	1.60	0.15
Lower leg (below knee, includes ankle and foot)	36	79,884	1.40	2.90	0.05
Shoulder and axilla	30	69,009	1.17	2.50	0.04
Unlisted code	28	23,310	1.09	0.90	0.12
Other procedures	17	3324	0.66	0.10	0.51
Unknown	16	37,447	0.62	1.40	0.04
Burn excisions or debridement	13	546	0.51	0.00	2.38
Upper arm and elbow	12	18,248	0.47	0.70	0.07
Pelvis (except hip)	8	6585	0.31	0.20	0.12
Radiological services	2	1888	0.08	0.10	0.11

Concerning the duration of CPR, Randomized Clinical Trials are needed to elucidate this, as current studies showed that in the operating room, we can extend the duration of CPR, as the early detection allows for minimal no-flow state. A study by Chaparov et al. showed that a ROSC can be achieved even 50 minutes after the onset of the CA (109). As for the postoperative consequences of these events. Recent studies are showing a continuous increase in survivorship (110). In this series by Sprung et al., including more than 513394 anaesthetised patients, survival at hospital discharge was at 34,5%. But night shifts and weekends are still correlating with lower survivorship (111).

Table XI: Summary of frequent causes of cardiac arrests in the operating room induced by anesthesia.

<p>Respiratory causes</p> <ul style="list-style-type: none"> - Difficult intubation, airway obstruction - Dysfunction of the anesthesia machine (technical failure, hypoxic gas mixture, incorrect settings of the ventilator, disconnection...) - Barotrauma, gastric inhalation, - Respiratory depression (during vigil anesthesia, induction of locoregional anesthesia...)
<p>Adverse effects of anesthesia or adjuvant agents</p> <ul style="list-style-type: none"> - IV or inhalation overdose - Anaphylactic reaction - Drug interference (CEI inhibitors...) - Association with hypovolaemia (locoregional anesthesia...-)
<p>Cardiovascular causes</p> <ul style="list-style-type: none"> - Pulmonary edema - Rhythm or conduction disturbances (dyskalemia, etc.) - Cardiac ischemia - Embolisms - Parasympathetic stimulation, etc.

B. Etiologies

General Factors A study about the safety outcomes following Neurosurgery from the American College of Surgeons National Surgical Quality Improvement Program Database (ACS-NSQIP), confirmed first that cranial surgery had 2,73 higher risk of mortality compared to spinal surgery (112). Several predictors were also associated with complications, including the ethnicity, tobacco use, dyspnea, COPD, chronic heart failure, paradoxically an increased body-mass index was protective. Another study from a Teaching

hospital, and over 10 years (113) showed the predictive value of ASA Scores, and that patients with Level V ASA physical status had more than 353 more chances of having a Cardiac arrest than 1 or 2.

Table XII: ASA Physical Status Classification System (114)

ASA PS Classification	Definition	Adult Examples, Including, but not Limited to:	Pediatric Examples, Including but not Limited to:
ASA I	A normal healthy patient	Healthy, non-smoking, no or minimal alcohol use	Healthy (no acute or chronic disease), normal BMI percentile for age
ASA II	A patient with mild systemic disease	Mild diseases only without substantive functional limitations. Current smoker, social alcohol drinker, pregnancy, obesity (30<BMI<40), well-controlled DM/HTN, mild lung disease	Asymptomatic congenital cardiac disease, well controlled dysrhythmias, asthma without exacerbation, well controlled epilepsy, non-insulin dependent diabetes mellitus, abnormal BMI percentile for age, mild/moderate OSA, oncologic state in remission, autism with mild limitations
ASA III	A patient with severe systemic disease	Substantive functional limitations; One or more moderate to severe diseases. Poorly controlled DM or HTN, COPD, morbid obesity (BMI ≥40), active hepatitis, alcohol dependence or abuse, implanted pacemaker, moderate reduction of ejection fraction, ESRD undergoing regularly scheduled dialysis, history (>3 months) of MI, CVA, TIA, or CAD/stents.	Uncorrected stable congenital cardiac abnormality, asthma with exacerbation, poorly controlled epilepsy, insulin dependent diabetes mellitus, morbid obesity, malnutrition, severe OSA, oncologic state, renal failure, muscular dystrophy, cystic fibrosis, history of organ transplantation, brain/spinal cord malformation, symptomatic hydrocephalus, premature infant PCA <60 weeks, autism with severe limitations, metabolic disease, difficult airway, long term parenteral nutrition. Full term infants <6 weeks of age.
ASA IV	A patient with severe systemic disease that is a constant threat to life	Recent (<3 months) MI, CVA, TIA or CAD/stents, ongoing cardiac ischemia or severe valve dysfunction, severe reduction of ejection fraction, shock, sepsis, DIC, ARD or ESRD not undergoing regularly scheduled dialysis	Symptomatic congenital cardiac abnormality, congestive heart failure, active sequelae of prematurity, acute hypoxic-ischemic encephalopathy, shock, sepsis, disseminated intravascular coagulation, automatic implantable cardioverter-defibrillator, ventilator dependence, endocrinopathy, severe trauma, severe respiratory distress, advanced oncologic state.
ASA V	A moribund patient who is not expected to survive without the operation	Ruptured abdominal/thoracic aneurysm, massive trauma, intracranial bleed with mass effect, ischemic bowel in the face of significant cardiac pathology or multiple organ/system dysfunction	Massive trauma, intracranial hemorrhage with mass effect, patient requiring ECMO, respiratory failure or arrest, malignant hypertension, decompensated congestive heart failure, hepatic encephalopathy, ischemic bowel or multiple organ/system dysfunction.
ASA VI	A declared brain-dead patient whose organs are being removed for donor purposes		

Anaphylaxis during surgery affects about 1 in 4,000 to 1 in 20,000 people (115). Between 1998 and 2000, bacitracin irrigation was described in several anaphylaxis episodes. During general anesthesia, the causing effect can also be neuromuscular blocking agents, latex, or antibiotics, and flushing, urticaria, and edema occurred in nearly 75% of anaphylactic episodes (116).

As discussed in the chapter related to patients' safety, last years were synonymous of an increase of awareness about the importance of non-technical and environmental aspects in the clinical outcomes of surgeries. In a perioperative setting, Lagasse described 2 categories of errors, systematic error and human errors (Source). Concerning numbers of related cardiac arrests

Position-related Factors As discussed in the previous chapters, neurosurgery has a lot of different positioning adapted to the type and location of the surgery. These positions can also bring a lot of challenges to the operating team in case of a cardiac emergency and the need of CPR especially with the head fixation.

A systematic review by M.Kwee at al. showed that the prone position during surgery is associated with physiological changes with a decrease in stroke volume, cardiac index. This can even lead to cardiovascular severe adverse events and even asystole, if associated with other risk factors like VAE, Cardiac comorbidities, Hemorrhage (117). Prone, Lateral, Concorde and other specific positions are not adapted to the normal chest compressions nor the defibrillation. Even if most cardiac events are momentaneous and resolving, patients requiring proper CPR will need considerable effort to be turned to supine position. CPR is well codified in supine position (118), however as for the prone position, no specific guidelines are available, but the AHA guidelines

recommend returning the patient, and proceeding only to a prone CPR if the patient cannot be moved (119). Existing theories about CPR physiology might suggest that prone CPR is effective. This heart-pump theory describes how compressions press the heart between the front wall of the spine and the sternum, causing a flow in the systemic and pulmonary circulations. Although CPR has been used successfully in lateral and sitting positions (120), and specifically in neurosurgery where some cases were reported, however there are no standard recommendations for managing patients in these situations (121).



Figure 35: Location where compressions are recommended to be performed in the prone position. Red line represents the location of compressions. Black line represents the inferior scapular limit.

Venous Air Embolism is a serious neurosurgical adverse event. Unfortunately all neurosurgical procedures are all vulnerable to the condition, but the risk is increased in the sitting and semi-sitting positions (122). The incidence is not clear and might vary from 15% to 80% depending on the detection method (transesophageal echocardiography or precordial doppler) (123). Often resulting in minimal clinical and physiological effect, the VAE can sometimes result in hemodynamic or neurological compromise motivating an urgent change to the patients' positions. VAE can only occur if two conditions

are confirmed, when the venous system is exposed to the environment, and when there is a pressure differential, which leads to air inflow into the venous system. VAE can be evoked based on capnography (drop of end tidal CO₂ levels) associated with a decrease in blood pressure. Other diagnosis methods include precordial doppler and transesophageal echocardiography (TEE). TEE is an invasive procedure, but its sensitivity to detect air embolism is the highest. However, a trial in India, with more than 140 neurosurgical patients, showed that VAE that is only detected in TEE and not detected on capnography is unlikely to cause any serious hemodynamic change (124).

Surgical Factors and Manipulation

TrigeminoCardiac Reflex is a recognized physiological reflex, causing circulation and cardiac events (Bradycardia, hypotension, or asystole) in neurosurgery, ophthalmic and Ears Nose and Throat Surgery (125,126). It was described for the first time by the italian Bernard Ascher and Guiseppe Dagnini. It was first described as the oculo-cardiac effect (OCR) as it was known to only affect the ophthalmic branch of the Trigeminal Nerve but the terminology was changed to TCR .

The mechanism of TCR is not completely elucidated, but the current evidence shows that the TCR is as a result of the direct or indirect stimulation (mechanical, stretching, thermal, electrical) of the trigeminal nerve or its branches. The arc starts by the confluence of all the endings of the trigeminal nerve to the Gasserian ganglion, then to the sensory nucleus of CN V in the Pons. These neurons will then join the motor nucleus of the vagus nerve from which the cardioinhibitory fibers will arise and terminate in the heart. The activation of the reflexe causes a negative chronotropic and inotropic response inducing the bradycardia and the hypotension (127).

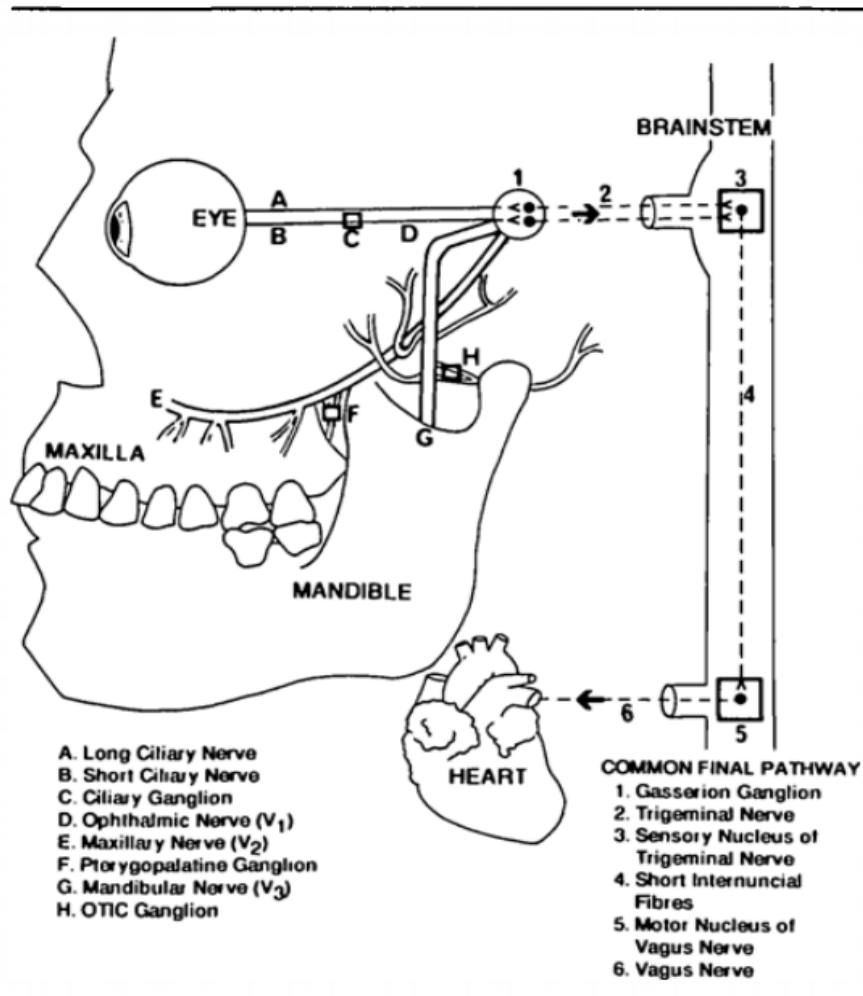


Figure 36: Trigemino-Cardiac pathways

Several risk factors are associated with the occurrence of the TCR , including age, hypercapnia, hypoxemia and the anesthesia (128). With this regard, the best-known anesthetic drug responsible for TCR is Fentanyl in the young population, however Propofol, as a commonly used anesthetic, is not fully evaluated in TCR and this study showed also that there is a statistical difference between patients, who previously had an infarctus and those who did not, as TCR was more frequent in the population with previous cardiac infarctus (129).

A study from A. Koerbel et al. described a series of 200 patients admitted for skull base surgery in which 8% (16 patients) had a TCR with no impact on the mortality (130). This showed that the TCR can be a common event in neurological surgery, due to the diverse surgical approaches near the trigeminal nerve. However, stopping surgical stimulation was sufficient to reestablish HR and blood pressure to normal levels, thus CPR is rarely required (127). Another case report showed the use of anticholinergic drugs to increase the heart rate (131). This is why it is important to closely monitor hemodynamic parameters, and detect the occurrence of the TCR and act accordingly. Moreover, studies about the postoperative consequences of TCR did not report any postoperative clinical consequences (132).

Hypothalamic stimulation was also described in the literature as causing cardiac arrhythmias including asystole. A study by Attar et al. showed that stimulation of anterior hypothalamus resulted in bradycardia, and the stimulation of lateral and posterior hypothalamus resulted in transient premature beats and a Auriculo-Ventricular dissociation (133). A Case study by Girija et al. described a case of a transient asystole in a patient with no history of associated cardiac disease, who underwent a transsphenoidal pituitary surgery (134).

Amygdaloid complex stimulation and other manipulations were also associated with hemodynamic disturbances; this concerns different parts (Insular Cortical, Limb). Kumar et. Al, described 3 cases of severe bradycardia and asystole occurring in patients undergoing anterior temporal lobectomy and amygdalo-hippocampectomy for the treatment of epilepsy (136). However as with other surgical simulations, stopping the stimuli resolved the case. **Vagal stimulation** was also described to cause hemodynamic and cardiac complications (135). Some cases of CA caused by **glossopharyngeal vagal reflexes** were described in the posterior fossa surgery (136).

Baroreceptor Reflex (BRR) is a physiological mechanism to control blood pressure at normal levels that can be triggered by stimulation of the carotid sinus, causing bradycardia and hypotension in some sensitive patients.

C. Diagnosis

Diagnosis of Cardiac arrest in the operating room is relatively simple compared to other situations, as the majority of patients are closely monitored. However, it is important to emphasize that other signs of cardiac arrest can be masked. The loss of consciousness is masked by the anesthesia, and the respiratory arrest is also masked by the mechanical ventilation. Thus, it is important to monitor and detect early signs of CA.

Monitoring is an important pillar of anesthesia perioperative care. With the development of patients' safety protocols, like the American Society of Anesthesia standards for basic anesthetic monitoring (137), there is a great emphasis on monitoring blood oxygenation (Pulse Oximetry), Ventilation (expired end-tidal carbon dioxide), Invasive and non-invasive blood pressure, and electrocardiogram monitoring. These tools will help detect, guide the resuscitation, the execution of a quality CPR (138) and indicate the return of spontaneous circulation (ROSC) .

Electrocardiogram Monitoring

ECG monitoring is a powerful tool that confirms the diagnosis of the IOCA. The monitor can also precise the type : Asystole, Ventricular Fibrillation, Pulseless Electrical Activity and Arrhythmias. It can also help detect early signs : Bradycardia, tachycardia, ST elevation, and orient the therapeutic management of cardiac arrest.

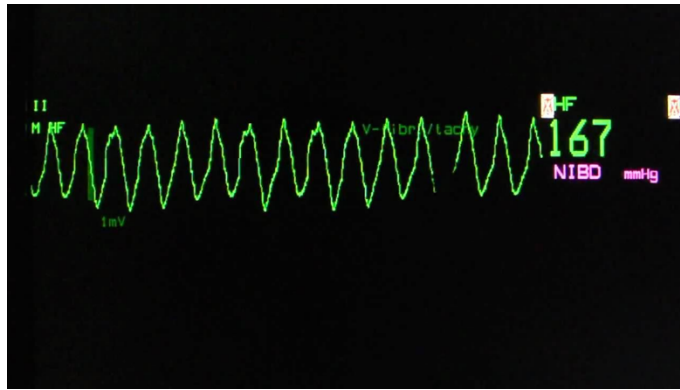


Figure 37: ECG Monitor showing a Ventricular Tachycardia at 167 bpm

The ECG is then the main tool to predict the event on the appearance of arrhythmias. (eg, bradycardia before asystole; polymorphic ventricular tachycardia and / or extrasystole before VF). Finally, the early detection of the event depends on the setting of the alarm terminals and the reliability of the trace.

Pulse Oximetry

In anesthesia, the pulse oximeter is a commonly used non-invasive device allowing continuous monitoring of tissue oxygenation. These characteristics made it a great revolution for patients' safety (139). The device is using the optical observance method to detect and visualise the saturation of oxyhemoglobin. A value of 92%, means that the red cells are full of 92% of oxyhemoglobin and 8% of deoxyhemoglobin.

Pulse Oximetry is a great tool to monitor the respiratory functions, but also can detect early signs of cardiac arrest due to a decrease of cardiac output, and anoxia. An asystole is transcribed as a disparition of the plethysmographic line, but even before the occurrence of the cardiac arrest, a decrease of the saturation

and the absence of the plethysmographic oscillations can be observed. However different scenarios can reduce its value, especially as desaturation in CA can happen at a later time. Moreover, pulse oximetry can be unreliable during hypoperfusion states (140), Carboxyhemoglobin, and a low Arterial O₂ Saturation. Studies have found that if arterial saturation is > 90% , SpO₂ values have 4% CI, and this confidence interval increases if arterial saturation is below 90% (141).

Capnography and End-Tidal Expiratory Pressure of Carbon Dioxide :

Capnometry is the measure of carbon dioxide (CO₂) in expired air, Capnography is the graphical representation of CO₂ during respiratory cycles. They are a powerful tool to detect and guide cardiac resuscitation especially in intraoperative settings (138). Monitoring capnography waveform allows to confirm correct placement of the ETT, monitor the quality of chest compressions, and detect a ROSC. Some studies also linked a high ETCO₂ value (>10 mmHg) with unsuccessful outcomes and prognosis (142).

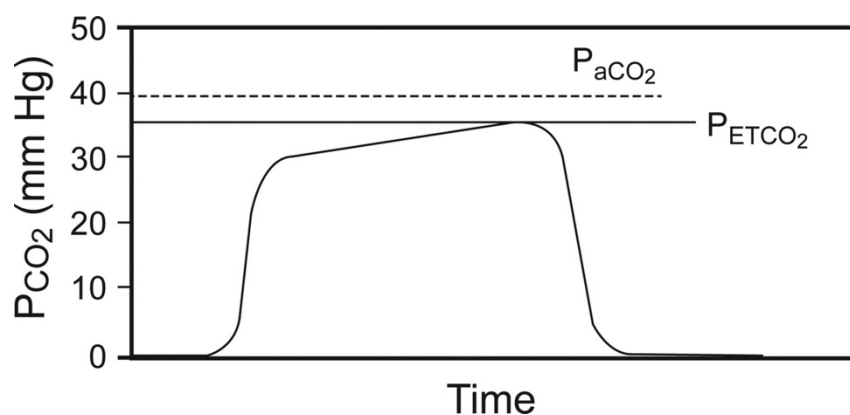


Figure 38: Normal Capnogram showing the ETCO₂ variation and the comparison with the PaCO₂ (143)

CO₂ is a metabolite, produced by cells after aerobically, it is then transported to the alveoli where it is exchanged for O₂. Thus, ETCO₂ provides a holistic view on metabolism, circulation and ventilation as its determinants include alveolar and lung perfusion, ventilation, the CO₂ production, and the cardiac input (144). A sudden decrease in ETCO₂ should evoke a circulatory failure and is a great predictive sign of a Cardiac arrest and can even evaluate the efficiency of the CPR and detect ROSC (145). While performing CPR, Physicians can witness an increase of ETCO₂ then a small decline to a stable value that translates in a ROSC (146). An experimental study in dogs showed that a 25% decrease in Cardiac Output is translated in a 20% decrease in PetCO₂ (147). This sudden decrease can happen before the manifestation of any Cardiac arrhythmia, or the decrease of Blood pressure which make it a great predictive indicator during surgeries. We also consider a PetCO₂ < 10 mmHg synonym of a circulatory failure and an early sign to start CPR(148). However it is important to know that ETCO₂ is not a specific measure, as it can be decreased in different other conditions like the pulmonary embolism (149).

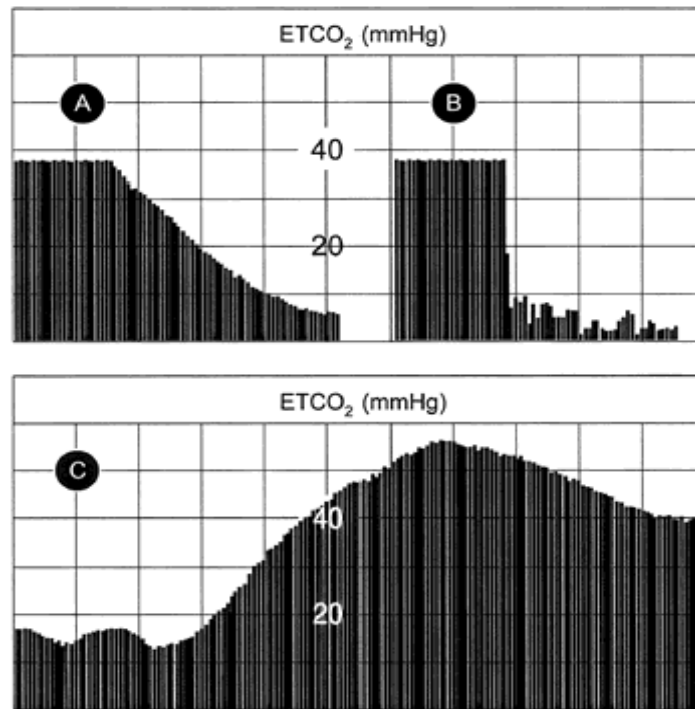


Figure 39: Three Different Capnograms A) progressive decrease in PETCO₂ during circulatory failure; B) Sudden Decrease in PETCO₂ during accidental disconnection of the breathing circuit; C) Monitoring PETCO₂ during CPR

Invasive Blood pressure can help diagnose, by showing a pulseless aretrial activity, it will also help monitor the effectiveness of CPR. If it is an uncommon tool used in surgery, as the gold standard is non-invasive intermittent measures of blood pressure, the Invasive blood pressure lines can be a valuable tool especially for high risk patients.

D. Management specificities

The perioperative monitoring of patients allows for an immediate diagnosis and early signs of cardiac arrest. In case of a diagnosed IOCA, it is important to start by stopping any perfused or inhaled anesthesia and follow the guidelines developed by the SFAR to search for an etiological diagnosis of cardiac arrest. If Ventilation is efficient, start immediate CPR.

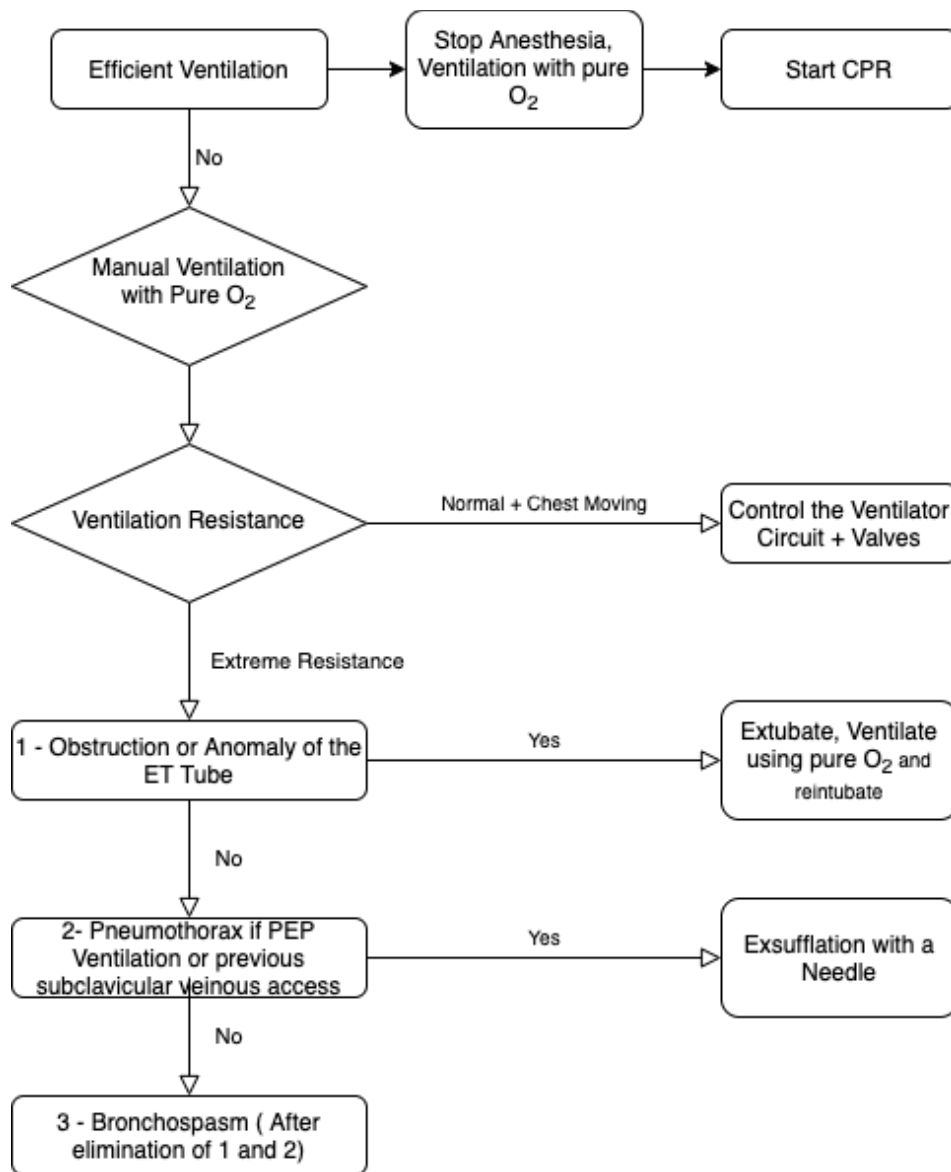


Figure 40: Adapted Diagram - Ventilation Control of an intubated patient with an IOCA. From the “Société Française d’Anesthésie et de Réanimation” (150)

The basic steps of the CA algorithm are based on the ILCOR, and main CPR Guidelines. However, some specific recommendations for Neurosurgery exist; like the United Kingdom Cardiac Arrest in Neurosurgery algorithm (Fig 41).

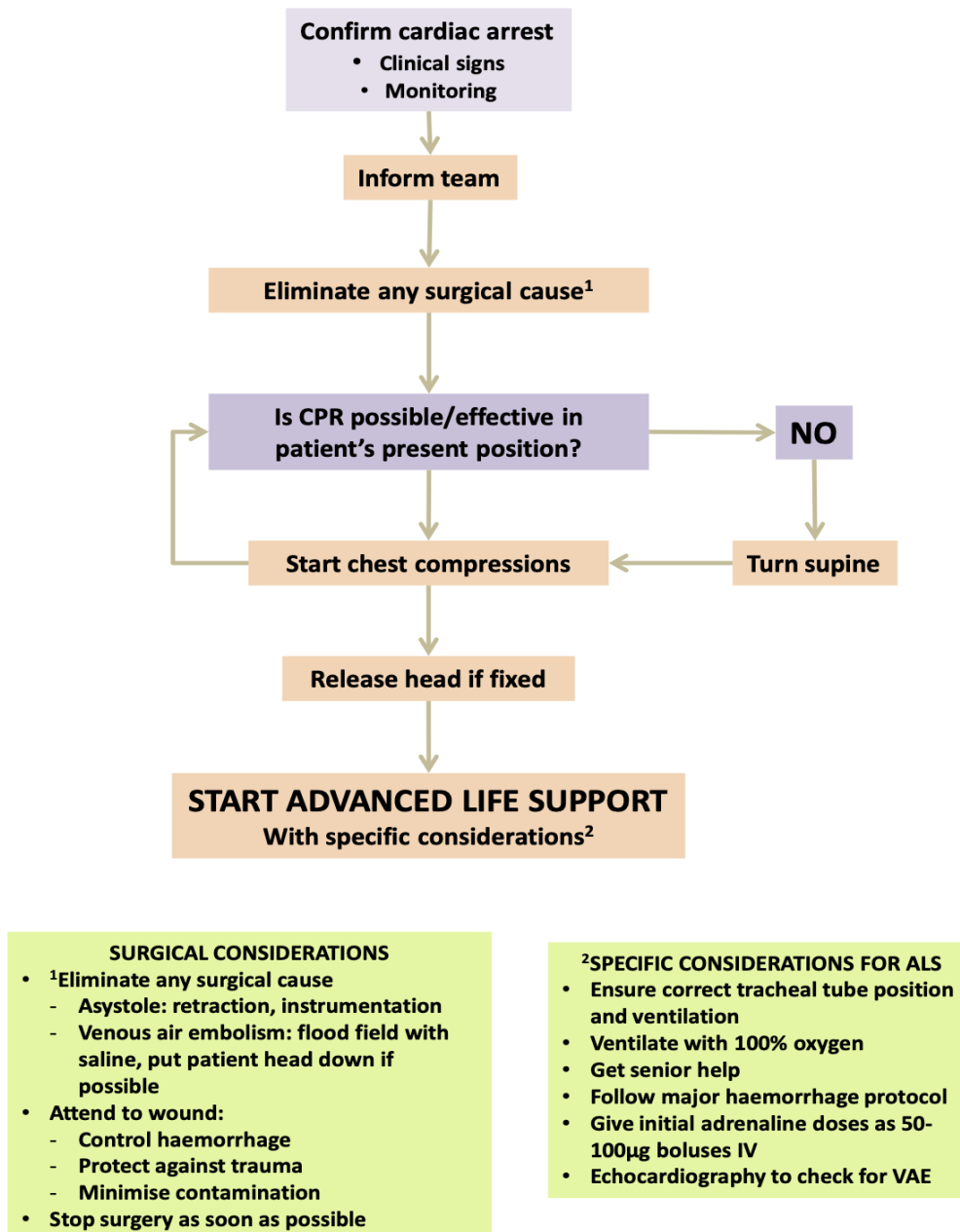


Figure 41: Cardiac Arrest in Neurosurgery Algorithm

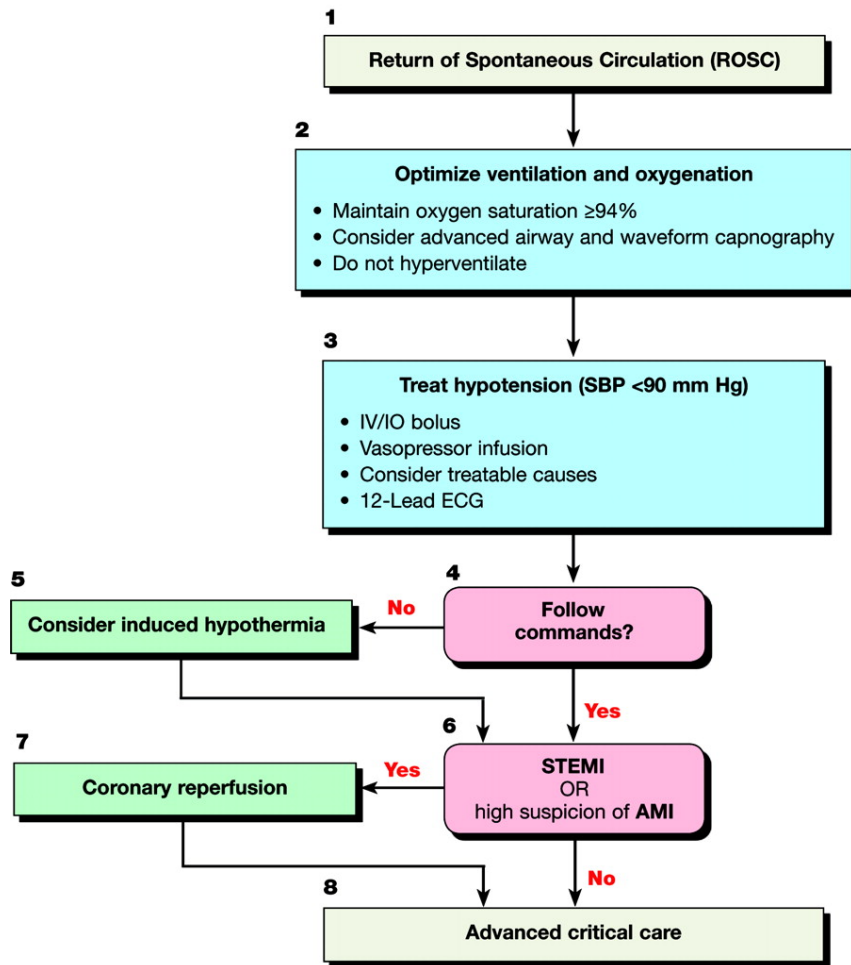
The Main difference with conventional ACLS is the initial dose of Epinephrine. The aim is to decrease the risk of rebound hypertension by giving minimal epinephrine dose (50-100 ug) instead of the conventional 1mg. The positioning should also be assessed by the operating team , and repositioning the patients is necessary if the current position doesn't allow effective and quality chest compressions. If position is supine, Chest compressions can start immediately, with an emphasis to release the head fixation should also be released, as continuing chest compression with a fixed skull, can cause serious damage to scalp injury and spine. If position is Lateral, the operating team should turn the patient supine for optimal CPR, even if chest compressions were described in lateral position but their efficiency is unknown. In the sitting position, chest compressions will be difficult to execute, thus placing the patient in supine is recommended. On the other hand, chest compressions can be started immediately for prone patients; some studies confirmed the efficacy of back compressions but patients should be turned supine if possible (151).

Table XIII: Summary of key steps in management of different positions during neurosurgery CA

Position	Management
Supine	Start immediate chest compressions, and relieve head fixation
Lateral	Turn supine, relieve head fixation, then start chest compressions
Sitting	Turn supine, relieve head fixation, then start chest compressions
Prone	Start immediate chest compressions, and relieve head fixation, turn supine if possible

Finally, investigating surgical causes is the most important step, Asystole caused by TCR, and VAE, and they should be always considered. If VAE is diagnosed, either by transoesophageal echocardiography or monitoring a sudden decrease of etCO₂ of 2 mmHg; specific treatment should be started. The treatment of VAE includes Saline solution flooding of the surgical field, changing patients' patient to supine or trendelenburg, and continuing fluid expansion and inotropes (Epinephrine). The pharmacological treatment is based on Epinephrine (1mg every 3-5min) that should be given for all etiologies. However, if it's not an asystole, Defibrillation (200 Joules) should be considered for all pulseless ventricular tachycardia and ventricular fibrillation. Return of Spontaneous Circulation can be assessed with ECG, Blood Pressure, however Capnography (Increase of +35 mmHg) is usually a more reliable indicator of ROSC than pulse palpation. Concerning post-ROSC management, in this period, the operating team should take the decision of continuing the operation, modifying it or rescheduling it. This post recovery period is a continuation of the CPR, and an emphasis was put on it with AHA adding it to the 2020 chain of survival. Regardless of the duration, and the type of the cardiac arrest, the physiological impact of this event is severe on the brain and major organs. If ROSC was obtained but the etiology of CA was still unknown, it is important then to investigate the causes and treat it rapidly (Reperfusion of a coronary artery disease, treatment of a pulmonary embolism, treatment of metabolic disturbances...). Evidence shows that post-care management should involve hemodynamic support, oxygenation and ventilation, targeted temperature management (reducing T° to 33-33 C°)

Adult Immediate Post-Cardiac Arrest Care



Doses/Details

Ventilation/Oxygenation
Avoid excessive ventilation. Start at 10-12 breaths/min and titrate to target PETCO₂ of 35-40 mm Hg. When feasible, titrate FIO₂ to minimum necessary to achieve SpO₂ ≥94%.

IV Bolus
1-2 L normal saline or lactated Ringer's. If inducing hypothermia, may use 4°C fluid.

Epinephrine IV Infusion:
0.1-0.5 mcg/kg per minute (in 70-kg adult: 7-35 mcg per minute)

Dopamine IV Infusion:
5-10 mcg/kg per minute

Norepinephrine IV Infusion:
0.1-0.5 mcg/kg per minute (in 70-kg adult: 7-35 mcg per minute)

Reversible Causes

- Hypovolemia
- Hypoxia
- Hydrogen ion (acidosis)
- Hypo-/hyperkalemia
- Hypothermia
- Tension pneumothorax
- Tamponade, cardiac
- Toxins
- Thrombosis, pulmonary
- Thrombosis, coronary

Figure 42: Post-Cardiac Arrest Care Algorithm



Conclusion



Cardiac complications including VT, VF, PEA and Asystole during neurosurgery are rare but dreadful events. In our series, we identified 4 patients in more than 196 surgeries conducted in the Mohammed V Instruction Military hospital of Rabat, Morocco. 2 out of the 4 cases were related to the surgical stimulation, and simply stopping the stimulus resulted in recovery, the 3rd case was related to a rare takotsubo stress cardiomyopathy and the 4th one to hyperkalemia.

In different series, intraoperative cardiac arrest occurrence was closely correlated to extreme ages (infants or elderly) and high ASA status. However, in neurosurgery, common reported cardiac severe complications were related to surgical stimulation (Trigeminocardiac reflex, hypothalamic region and brainstem). Moreover, patients' positioning, skull fixation, and the type of neurosurgical procedures make applying conventional ACLS guidelines.

Efforts were made during the last years to promote patients' safety and to train medical teams to detect and treat cardiac arrest. However, evidence is rare when dealing with neurosurgical patients, and more efforts are needed in understanding the etiologies, mechanisms and the specificities of its management. Elaboration of specific guidelines, promoting research and implementing adverse events and anesthesia clinical outcomes registry can be a great step to enhance patients' outcome after these severe events.



Abstracts



Abstract

Title: Severe Cardiac Complications in Perioperative Neurosurgery

Author: Saad CHAIBI

Keywords: Adverse Events, Perioperative Care, Cardiac Complications, Neurosurgery

During the last decade, the volume of global surgical procedures grew exponentially responding to an aging population and demographic changes. With all the advances in patients' safety and access to safe surgery and anesthesia, cardiac Arrest and other perioperative cardiac adverse events are still dreadful events with severe associated morbidity and mortality. Thus, it was important to understand the etiopathogeny of these events and propose adequate guidelines to prevent them, and also be prepared to manage them during neurosurgical settings characterized by the specific body and head positioning. We defined severe cardiac adverse events as any complication including ventricular fibrillation, pulseless electrical activity, asystole, or severe bradycardia (<40 / min) with hypotension; however, with the lack of clear definitions specific to the operating room, it is difficult to conduct exhaustive comparisons and analysis.

The objective of our work was to analyze 4 clinical cases of patients admitted in the Operating Rooms of the Mohammed V Instruction Military Hospital (HMIMV) who respected our definition of a perioperative cardiac complication. These observations and discussions are completed by a review of the etiopathogeny, diagnosis, and management of these events.

Cardiac Arrest during craniotomies is easily diagnosed because of the close perioperative monitoring, however, with the specific operating conditions (Head fixation, body position), these events can be difficult to manage, as venous access, airway access, and the possibility to conduct efficient CPR can be compromised. Finally, It is important to insist on the necessity of training and guidelines for these rare yet dreadful events.

Résumé

Titre: Complications Cardiaques Sévères en Neurochirurgie Péropératoire

Auteur: Saad CHAIBI

Mots clés: événements indésirables, soins périopératoires, complications cardiaques, neurochirurgie

Au cours de la dernière décennie, le volume des interventions chirurgicales mondiales a augmenté de façon exponentielle en réponse au vieillissement de la population et aux changements démographiques. Avec tous les progrès réalisés en matière de sécurité des patients et d'accès à une chirurgie et à une anesthésie sûres, l'arrêt cardiaque et d'autres événements indésirables cardiaques périopératoires restent des événements graves associés à une morbidité et une mortalité importantes. Ainsi, il était important de comprendre l'étiopathogénie de ces événements et de proposer des directives adéquates pour les prévenir, et également les traiter lors des opérations neurochirurgicales caractérisées par le positionnement spécifique du corps et de la tête. Nous avons défini les événements indésirables cardiaques sévères comme toute complication incluant la fibrillation ventriculaire, l'activité électrique sans pouls, l'asystolie, ou la bradycardie sévère (<40/min) avec hypotension ; cependant, en l'absence de définitions claires consensuelles spécifiques à la période peropératoire, il est difficile de mener des comparaisons et des analyses exhaustives.

L'objectif de notre travail était d'analyser 4 cas cliniques de patients admis au bloc opératoire de l'hôpital militaire d'instruction Mohammed V (HMIMV) qui respectaient notre définition de cas. Ces observations et discussions sont complétées par une revue de l'étiopathogénie, du diagnostic et de la prise en charge de ces événements.

L'arrêt cardiaque pendant les craniotomies est facilement diagnostiqué en raison de la surveillance périopératoire étroite, cependant, avec les conditions opératoires spécifiques (fixation de la tête, position du corps), ces événements sont très difficiles à traiter, vu que l'accès veineux, l'accès aux voies aériennes et la possibilité de mener une RCP peuvent être compromis. Enfin, il est important d'insister sur la nécessité d'une formation et de mise en place de directives pour ces événements rares mais avec des conséquences graves.

ملخص

العنوان: المضاعفات القلبية الحادة أثناء عمليات جراحة الأعصاب

المؤلف: سعد الشعبي

الكلمات الأساسية : العناية أثناء العمليات الجراحية، جراحة الأعصاب، المضاعفات القلبية الحادة

خلال العقد الماضي، نما حجم العمليات الجراحية بشكل كبير على مستوى العالم استجابة لتقدم الشيخوخة والتغيرات الديموغرافية. شهد العالم أيضاً تطورات عديدة في سلامة المرضى وبلوغ تخدير و جراحة آمنة للجميع، لكن السكتة القلبية والأحداث العكسية القلبية أثناء الجراحة هم أحداثٌ مصحوبة بنسبة مرضية ووفيات كثيرة. ولهذا كان من المهم فهم المسببات المرضية لهذه الأحداث واقتراح إرشادات مناسبة لمنعها ، وكذلك الاستعداد لعلاجها خلال جراحة الأعصاب التي تتميز بوضع الجسم والرأس المحدد. خلال عملنا، حددنا الأحداث الضائرة القلبية الحادة على أنها أي مضاعفات تشمل الرجفان البطيني ، أو النشاط الكهربائي غير النبضي ، أو السكتة القلبية ، أو بطء القلب الشديد (أقل من 40 / دقيقة) مع انخفاض ضغط الدم ؛ ولكن ، مع عدم وجود تعريفات موحدة عالمية، كان من الصعب إجراء مقارنات شاملة

كان الهدف من عملنا هو تحليل 4 حالات لمرضى تم إدخالهم في غرف العمليات في المستشفى العسكري الدراسي محمد الخامس الذين احترموا تعريفنا لمضاعفات القلب وقد تمت دراسة الملاحظات والمناقشات من خلال مراجعة المسببات المرضية والتشخيص علاج هذه الأحداث

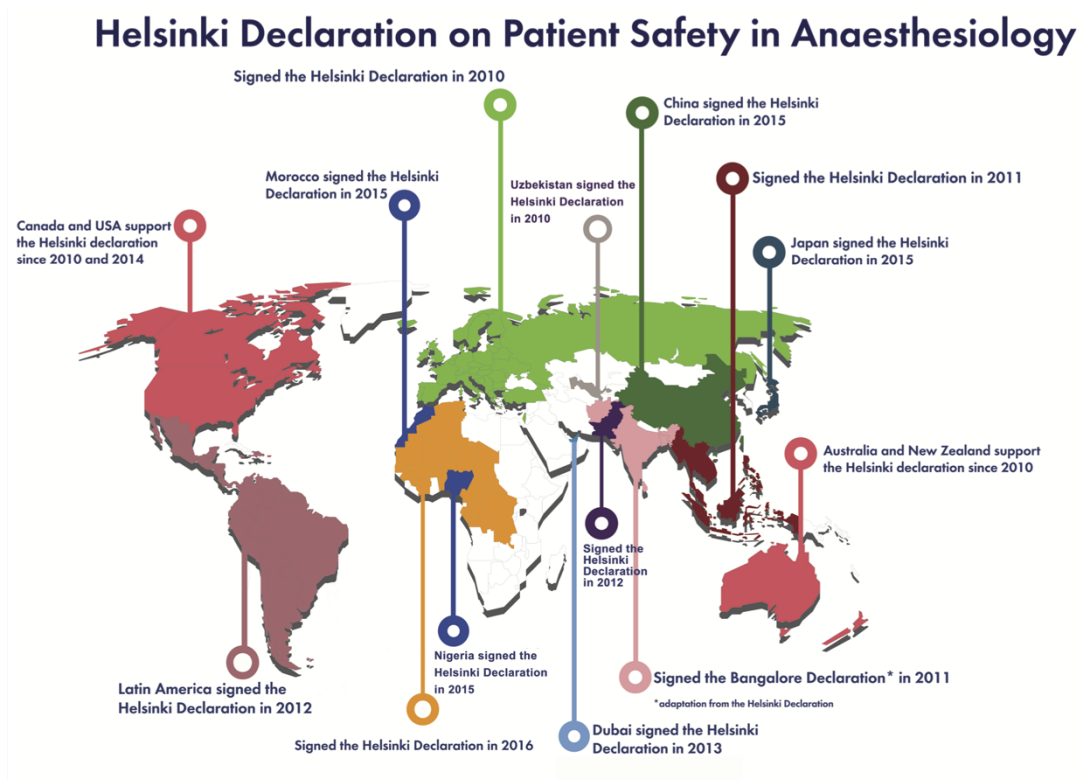
يمكن تشخيص توقف القلب أثناء عمليات شق القحف بسهولة بسبب المراقبة القريبة للجراحة ، ومع ذلك، مع ظروف التشغيل المحددة (تثبيت الرأس ، وضع الجسم) ، قد يكون من الصعب إدارة هذه الأحداث ، مثل الوصول إلى الوريد ، والوصول إلى مجرى الهواء ، وإمكانية إجراء العمليات بكفاءة يمكن اختراق الإنعاش القلبي الرئوي. أخيراً ، من المهم الإصرار على ضرورة التدريب والمبادئ التوجيهية لهذه الأحداث النادرة والمروعة.



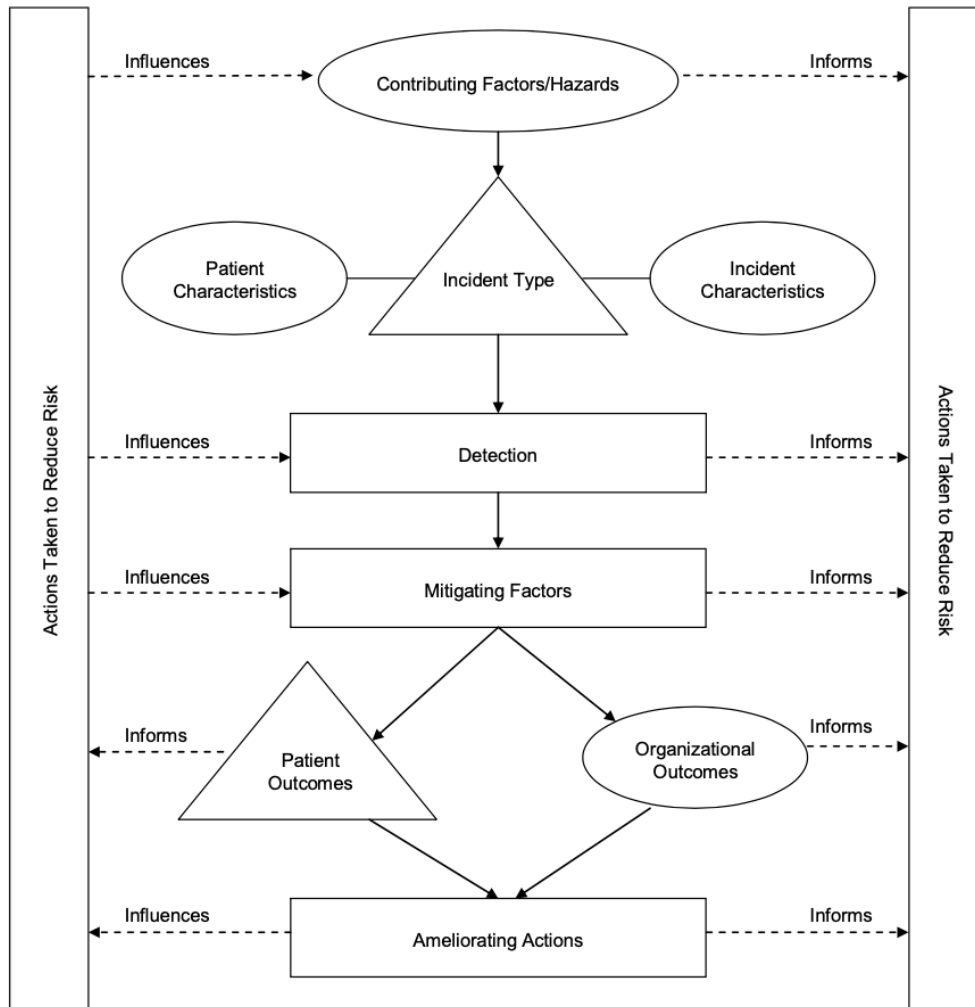
Appendix



II. Helsinki Declaration



III. Conceptual Framework for the International Classification for Patient Safety



- System Resilience (Proactive & Reactive Risk Assessment)
- △ Clinically meaningful, recognizable categories for incident identification & retrieval
- Descriptive information

The solid lines represent the semantic relationships between the classes. The dotted lines represent the flow of information.

IV. Neurosurgical Checklists

Authors & Year	Specialty	Aims	Outcomes
Fargen et al., 2012	vascular	standardize unique demands of neurointerventional procedures	after checklist implementation, total no. of adverse events was reduced by 35%, & 95% of staff championed checklist continuation
Kramer et al., 2012	stereotactic & functional neurosurgery	assess improvement in no. of errors w/ long-term checklist use	reduction in no. of errors after 1 yr of use, from 3.2 to 0.8 total errors per case
Da Silva-Freitas et al., 2012	general neurosurgery	evaluate a modified WHO surgical safety checklist on the safety & quality of care of neurosurgical pts	identification of 51 events in 44 ops; correction of 88% of errors prior to initiation of surgery
Matsumae et al., 2011	general neurosurgery	evaluate effect on surgical quality & communication	NA
Chen, 2011	vascular	design endovascular checklists in the event of aneurysm perforation & thromboembolic event	NA
Lyons, 2010	general neurosurgery	prevent rare errors, ensure correct imaging studies, & ensure antibiotic prophylaxis	no wrong-site, wrong-procedure, or wrong-patient error in 8 yrs of study; initiation of safety culture
Taussky et al., 2010	vascular	design endovascular checklist in event of aneurysm perforation during coil insertion	NA
Connolly et al., 2009	stereotactic & functional neurosurgery	detect & remediate procedural errors	no change in no. of errors; decreased time to complete checklist
NASS, 2001	spine	prevent wrong-site, wrong-level surgery	NA

* NA = not assessed.

V. Adverse events categorized by likely contributing factors

TABLE 1: Adverse events categorized by likely contributing factors*

Factor Category	Type of Surgery				
	Endovascular	Open Cerebrovascular	Shunt	Spine	Tumor
AEs related in part to surgical technique	thromboembolic events, access-related complications, intraprocedural rupture, failure to treat lesion	intraop rupture, incomplete obliteration, major vessel occlusion	intraabdominal complications, ICH	hardware-related complications, new deficit, hematoma, unintended durotomy	benign tumor recurrence, new/worsened deficit, CSF leak, postop hematoma
AEs related to periop medical management	thromboembolic events, groin-site hematoma, CIN	hemorrhage-related hyperglycemia, salt-wasting syndromes, new infarct, periop Sz	periop Sz	respiratory events, hardware-related complications, cardiac complications	postop peritumoral edema, postop Sz
AEs related to nonadherence to protocol	thromboembolic events, groin-site hematoma, CIN, radiation-induced effects	none known	infection	venous thromboembolism, wound infection, wrong-level surgery	venous thromboembolism, wound infection
AEs affected by preop optimization	thromboembolic events, groin-site hematoma, CIN	none known	none known	respiratory events, cardiac events	medical complications
AEs related to technology	radiation-induced effects	incomplete obliteration of target lesion, major vessel occlusion	valvular/mechanical dysfunction	hardware-related complications	WSS
AEs related to communication	none known	WSS	none known	none known	WSS

* Likely contributing factors other than patient condition. Abbreviations: AE = adverse event; CIN = contrast-induced nephropathy; ICH = intracerebral hemorrhage; Sz = seizure; WSS = wrong-site surgery.

VI. Physiological impact of positions in neurosurgery

	Cardiovascular	Respiratory	Central nervous	Benefits	Risks
Supine	<p>Compared to upright, awake and anesthetized:</p> <p>VR ↑, SV ↑, CO ↑</p> <p>HR ↓</p> <p>SVR ↓</p> <p>SBP ↔, MAP ↓ ↔</p>	<p>Compared to upright: FRC ↓, TLC ↓ atelectasis of the dependent lung zones;</p> <p>Qs/Qt ↑</p> <p>V/Q mismatch ↑</p>	<p>Compared to upright:</p> <p>JVF ↑ ↔</p> <p>JVR ↓ ↔</p> <p>CPP ↔ ↓</p> <p>CSF drainage may be impaired</p> <p><i>Improvement of the cerebral venous, lymphatic and CSF drainage.</i></p>	<p>The easiest position</p>	<p>Often needs head flexion/extension/rotation</p> <p>Ulnar and peroneal nerve injury</p>
<i>Modifications:</i>					
<i>a) lawn-chair</i>	<i>Improvement of the VR from the lower extremities</i>	<i>Improvement of ventilation of the dependent lung zones</i>			
<i>b) reverse Trendelenbourg</i>					
Lateral	<p>Compared to supine, anesthetized:</p> <p>VR ↓, SV ↓, CO ↓</p> <p>HR ↑ ↔</p> <p>SVR ↑, PVR ↑</p> <p>SBP ↓, MAP ↓</p>	<p>Compared to supine:</p> <p>FRC ↓, TLC ↓</p> <p>Qs/Qt ↑↑</p> <p>V/Q mismatch ↑↑</p> <p>atelectasis of the dependent lung</p>	<p>Compared to supine:</p> <p>JVF ↑ ↔</p> <p>JVR ↓ ↔</p> <p>with neck flexion:</p> <p>JVF ↓, JVR ↑, ICP ↑</p>	<p>Optimal approach to the temporal lobe</p>	<p>Brachial plexus injury</p> <p>Ear and eye injury</p> <p>Suprascapular nerve injury (of the dependent shoulder)</p> <p><i>Stretch injuries (axillary trauma)</i></p> <p><i>Decreased perfusion to the dependent arm</i></p>
<i>Modification:</i>					
<i>park-bench</i>					

	Cardiovascular	Respiratory	Central nervous	Benefits	Risks
Prone	<p>Compared to supine, awake: VR↓, SV↓ HR↑ ↔</p> <p>SVR↑, PVR↑</p> <p>SBP↔, MAP↔</p> <p>In anesthetized patient: VR↓, SV↓, CO↓↔ HR↑, SVR↑, PVR↑ SBP↓↔, MAP↓↔</p>	<p>Compared to supine: increase in upper airway resistance (Wilson frame and chest rolls)</p> <p>FRC↑ ↔, TLC↑ ↔</p> <p>V/Q mismatch ↓</p> <p>less atelectasis in lungs</p>	<p>Compared to supine: a) neutral to the heart</p> <p>JVF ↑ ↔</p> <p>JVR↓ ↔</p> <p>b) lower than heart</p> <p>JVF↑, JVR↓, venous congestion</p> <p>ICP↑</p>	<p>Optimal posterior approach to spine</p> <p>Less risk for VAE (compared to sitting)</p>	<p>The most difficult position</p> <p>Difficult access to airway</p> <p>Pressure sores of soft tissues</p> <p>Eye injury</p> <p>Blindness</p> <p>Bleeding (compared to sitting)</p>
<i>Modification: Concorde</i>					<p><i>Neck and head hyperflexion: venous congestion of the face, nose, and tongue, epistaxis, chin necrosis, cerebral venous obstruction, increase of ICP, quadriplegia</i></p>
Sitting	<p>Compared to supine, awake: VR ↓, SV ↓, CO↓</p> <p>HR↑, SVR↑, PVR↑</p>	<p>Compared to supine: TLC ↑, FRC ↑ Qs/Qt↓</p> <p>V/Q mismatch ↓</p>	<p>Compared to supine: JVF ↓, JVR ↑</p> <p>ICP↓↓</p> <p>CPP ↔</p>	<p>Optimal approach to posterior fossa</p> <p>Low ICP</p> <p>Minimal bleeding (compared to</p>	<p>Venous air embolism (VAE)</p> <p>Paradoxical air embolism</p> <p>Arterial Hypotension</p> <p>Pneumocephalus</p> <p>Paraplegia, Quadriplegia</p> <p>Macroglossia</p>

	Cardiovascular	Respiratory	Central nervous	Benefits	Risks
	SBP↑↔↓, MAP↓ ↔↑ In anesthetized patient: VR↓↓, SV↓, CO↓ HR↑, SVR↑, PVR↑ SBP↓, MAP↓	less atelectasis in lungs	Good cerebral venous and CSF drainage	prone) Access to airway	
Three - quarters	different changes, resemble lateral or prone	changes, resemble lateral or prone	different changes, resemble lateral or prone	Less risk for VAE (compared to sitting) Better access to airway (compared to prone)	Difficult position Brachial plexus injury Pressure sores Compartment syndrome of the dependent upper extremity Pudendal nerve injury

Changes of physiologic parameters in cardiovascular, respiratory and central nervous system are presented as observed in anesthetized subjects, changes in cardiovascular system presented in awake and anesthetized subjects: HR- heart rate, SV-stroke volume, VR – venous return, CO-cardiac output, SBP- systolic blood pressure, TLC- total lung capacity, FRC- functional residual capacity, Qs/Qt – intrapulmonary shunt, V/Q mismatch-ventilation/perfusion mismatch, ICP- intracranial pressure, JVF – jugular venous flow, JVR – jugular venous resistance, CPP- cerebral perfusion pressure; ↑- increase, ↓ - decrease, ↔ no change.

VII. Table 1. Incidence and 95% CI of Intraoperative Cardiac Arrest per 10,000 Surgeries by Pre- and Intraoperative Characteristics, American College of Surgeons National Surgical Quality Improvement Program, 2005–2007

Characteristic	No. of Surgeries* (n = 362,767)	Number of Intraoperative Cardiac Arrests (n = 262)	Incidence per 10,000 Surgeries (95% CI)
Age, yr			
16–49	138,804	34	2.45 (1.63–3.27)
50–69	143,127	98	6.85 (5.49–8.20)
≥70	80,834	130	16.08 (13.32–18.85)
Sex			
Female	208,918	110	5.27 (4.28–6.25)
Male	153,829	152	9.88 (8.31–11.45)
Race			
White	256,798	183	7.13 (6.09–8.16)
Black	35,339	27	7.64 (4.76–10.25)
Other/unknown	70,630	52	7.36 (5.36–9.36)
Body mass index, kg/m ²			
<25	108,584	76	7.00 (5.43–8.57)
25–<30	108,658	66	6.07 (4.61–7.54)
30–<40	95,177	53	5.57 (4.07–7.07)
≥40	39,295	9	2.29 (0.79–3.79)
Surgical-risk level†			
Low/ moderate risk	346,048	180	5.20 (4.44–5.96)
High risk (vascular)	16,719	82	49.05 (38.46–59.64)
Emergency surgery‡			
No	315,352	97	3.08 (2.46–3.69)
Yes	47,415	165	34.80 (29.50–40.10)
Resident surgeon participation			
No	131,083	64	4.88 (3.69–6.08)
Yes	220,053	190	8.63 (7.41–9.86)
ASA physical status classification			
1–2	206,879	18	0.87 (0.46–1.27)
3	131,007	67	5.11 (3.89–6.34)
4	22,794	98	42.99 (34.50–51.49)
5	1,145	78	681.22 (535.07–827.38)
Functional health status before surgery§			
Independent	337,775	108	3.20 (2.59–3.80)
Partially or totally Dependent	24,992	154	61.62 (51.92–71.32)
Dyspnea			
No	321,006	175	5.45 (4.64–10.96)
Moderate exertion	36,254	40	11.03 (7.62–14.45)
At rest	5,507	47	85.35 (61.04–109.65)
Severe chronic obstructive pulmonary disease			
No	346,337	226	6.53 (5.67–7.38)
Yes	16,430	36	21.91 (14.76–29.06)
Current smoker within 1 yr			
No	286,386	198	6.91 (5.95–7.88)
Yes	76,381	64	8.38 (6.33–10.43)

Heart disease			
No	322,312	163	5.06 (4.28–5.83)
Yes	40,455	99	24.47 (19.66–29.29)
Hypertension requiring medications			
No	202,194	94	4.65 (3.71–5.59)
Yes	160,573	168	10.46 (8.88–12.04)
Impaired sensorium#			
No	359,312	220	6.12 (5.31–6.93)
Yes	3,455	42	121.56 (85.01–158.12)
Coma**			
No	362,452	244	6.73 (5.89–7.58)
Yes	315	18	571.43 (313.70–829.16)
Cerebrovascular disease††			
No	338,849	219	6.46 (5.61–7.32)
Yes	23,918	43	17.98 (12.61–23.35)
Spinal disorder‡‡			
No	360,838	258	7.15 (6.28–8.02)
Yes	1,929	4	20.74 (0.41–41.05)
Renal disease§§			
No	353,129	221	6.26 (5.43–7.08)
Yes	9,638	41	42.54 (29.54–55.54)
Diabetes mellitus with oral agents or insulin			
No	311,481	203	6.52 (5.62–7.41)
Yes	51,286	59	11.50 (8.57–14.44)
Preoperative sepsis			
No	328,804	139	4.23 (3.52–4.93)
SIRS /sepsis	30,212	58	19.20 (14.26–24.13)
Septic shock	3,751	65	173.29 (131.51–215.07)
Bleeding disorders			
No	341,136	202	5.92 (5.11–6.74)
Yes	21,631	60	27.74 (20.73–34.75)
Transfusion of > 4 units of packed erythrocytes in 72 h before surgery			
No	361,194	242	6.70 (5.86–7.54)
Yes	1,573	20	127.15 (71.72–182.57)
No. of erythrocyte units transfused intraoperatively			
0	343,054	98	2.86 (2.29–3.42)
1–3	14,937	42	28.12 (19.63–36.61)
4–6	3,103	38	122.46 (83.74–161.18)
7–9	694	16	230.55 (118.62–342.48)
≥10	786	64	814.25 (622.64–1005.86)



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Serment d'Hippocrate

Au moment d'être admis à devenir membre de la profession médicale, je m'engage solennellement à consacrer ma vie au service de l'humanité.

- *Je traiterai mes maîtres avec le respect et la reconnaissance qui leur sont dus.*
- *Je pratiquerai ma profession avec conscience et dignité. La santé de mes malades sera mon premier but.*
- *Je ne trahirai pas les secrets qui me seront confiés.*
- *Je maintiendrai par tous les moyens en mon pouvoir l'honneur et les nobles traditions de la profession médicale.*
- *Les médecins seront mes frères.*
- *Aucune considération de religion, de nationalité, de race, aucune considération politique et sociale ne s'interposera entre mon devoir et mon patient.*
- *Je maintiendrai le respect de la vie humaine dès la conception.*
- *Même sous la menace, je n'userai pas de mes connaissances médicales d'une façon contraire aux lois de l'humanité.*
- *Je m'y engage librement et sur mon honneur.*

قسم أبقراط

بسم الله الرحمان الرحيم أقسم بالله العظيم

في هذه اللحظة التي يتم فيها قبولي عضوا في المهنة الطبية أتعهد علانية:

- ◀ بأن أكرس حياتي لخدمة الإنسانية.
 - ◀ وأن أحترم أساتذتي وأعترف لهم بالجميل الذي يستحقونه.
 - ◀ وأن أمارس مهنتي بوازع من ضميري وشرفي جاعلا صحة مريضى هدفي الأول.
 - ◀ وأن لا أفشي الأسرار المعهودة إلي.
 - ◀ وأن أحافظ بكل ما لدي من وسائل على الشرف والتقاليد النبيلة لمهنة الطب.
 - ◀ وأن أعتبر سائر الأطباء إخوة لي.
 - ◀ وأن أقوم بواجبي نحو مرضاي بدون أي اعتبار ديني أو وطني أو عرقي أو سياسي أو اجتماعي.
 - ◀ وأن أحافظ بكل حزم على احترام الحياة الإنسانية منذ نشأتها.
 - ◀ وأن لا أستعمل معلوماتي الطبية بطريق يضر بحقوق الإنسان مهما لاقيت من تهديد.
 - ◀ بكل هذا أتعهد عن كامل اختيار ومقسما بالله.
- والله على ما أقول شهيد.



المملكة المغربية
جامعة محمد الخامس بالرباط
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الرباط



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أطروحة

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السيد سعد الشعبي

المزاد في 01 يوليوز 1994 بالرباط

لنيل شهادة

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أعضاء لجنة التحكيم:

السيد خليل أبو العلاء

أستاذ في الإنعاش والتخدير

السيدة عزيزة بنطلحة

أستاذة في الإنعاش والتخدير

السيدة محجوبة بوطربوش

أستاذة في علم التشريح

رئيس ومشرف

عضو

عضو