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Title

Intensive Care Medicine in 2050: Managing cardiac arrest

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Survival rates after out-of-hospital cardiac arrest (OHCA) vary considerably worldwide and are highly dependent on the organization of emergency medical services (EMS), rates of bystander performing cardiopulmonary resuscitation (CPR), time to first defibrillation, quality of advanced life support (ALS) and post resuscitation care, i.e. the quality of the local chain of survival (LOS) (1). Health care systems that have implemented rigorous training and monitoring systems to strengthen weak links in the local LOS have arguably had the greatest impact on survival from cardiac arrest (2).

Given that early bystander CPR improves survival after cardiac arrest (3), CPR training for all should start at school age, not only to ensure early initiation of CPR, but also for early recognition of cardiac arrest and rapid alerting of the emergency medical communication centres (EMCC). Global positioning system (GPS)-enabled mobile-phones are already being used to dispatch trained lay volunteers to OHCA victims, thereby increasing rates of bystander-initiated CPR (4). By 2050, it is likely that enhancements in GPS and mobile communications will enable much faster and more precise responses by lay trained volunteers (Table 1). Early defibrillation improves survival and by 2050 we expect widespread deployment of relatively inexpensive and more sophisticated automated external defibrillators (AEDs) beyond the traditional first responders inside the EMS systems, thus decreasing the distance to the closest AED (5,6). Drones that can carry AEDs to the scene of a cardiac arrest are already being developed and by 2050 it is likely that EMCCs will have fully adopted this technology (7). In the future, the EMCCs will have highly effective protocols for identifying cardiac arrest and for providing telephone-guided CPR. Wireless technology and the use of biosensors are evolving rapidly – in the future it is likely that a patient with an impending OHCA can be detected remotely and then treated so that cardiac arrest is prevented.

ALS providers should focus on good quality CPR, defibrillation, airway management, drug therapy and use of more advanced adjuncts that might further improve haemodynamics (8). However, ALS will evolve beyond routine use of standardised drugs with a ‘one size fits all’ philosophy. Instead of using a standardised algorithm, injection of vasopressors is likely to be guided by the haemodynamic response, such as the diastolic aortic pressure (9). Furthermore, the timing of drug delivery as well as the drugs used (e.g., vasopressors, antiarrhythmics) will be individualised. Use of technologies such as capnography, near infrared spectrophotometry (NIRS), waveform analysis for optimizing shock delivery, (8) carotid Doppler blood flow measurements (10) and ultrasound examination (8) will enable haemodynamics during CPR to be optimised and individualised taking into account the cause of cardiac arrest. Use of more sophisticated mechanical chest compression devices is likely to become more widespread, either as a bridge to coronary angiography/percutaneous coronary intervention or to extracorporeal CPR (ECPR). By 2050, it is likely to be much easier to undertake ECPR for the treatment of refractory cardiac arrest, and therefore extending its existing availability from tertiary centres to most acute hospitals (11).

Most patients who have an in-hospital cardiac arrest (IHCA) will show signs of deterioration in the hours preceding the event. The most effective way of reducing mortality from IHCA is to recognise those at risk of cardiac arrest and either treat to prevent the cardiac arrest or make a do not attempt CPR (DNACPR) decision. By 2050, electronic medical records will be implemented widely, enabling automatic capture of vital sign data from wireless monitors and derivation of automated early warning scores. Such systems will enable efficient automatic alerting of the rapid response team that can then intervene and potentially prevent cardiac arrest. By 2050, the wide adoption of emergency care and treatment plans will mean that most in-patients will have discussed with hospital staff and agreed their emergency

treatment, including CPR, in advance. This will reduce or, ideally, eliminate futile resuscitation attempts in hospital.

When return of spontaneous circulation (ROSC) is obtained, finding and treating the cause of the cardiac arrest can prevent relapse and subsequent clinical deterioration. In this way, recent guidelines recommend that resuscitated patients of presumed coronary cause should undergo immediate coronary angiography with subsequent revascularisation if indicated (12). Although it presents some organisational challenges, a 24/7 coronary angiography should make available in all our future cardiac arrest centres. The principle challenge is to identify those cardiac arrest patients with a presumed coronary cause and to avoid taking patients without acute culprit lesions to coronary angiography. We hope that the future will give us better diagnostic tools (transportable CT, handheld echocardiography, early biomarkers), because an early ECG, performed on the scene of resuscitation immediately after ROSC, is insufficiently precise to detect or exclude acute culprit lesions responsible for the arrest. (13). Furthermore, it will become much easier to perform a coronary CT-scan at the time of hospital admission. This non-invasive strategy could be used in ‘low-risk patients’ (i.e., those without evidence of a coronary cause), since it will be possible to avoid further invasive procedures in those with a normal coronary CT-scan (14).

Post-resuscitation brain injury is the commonest cause of death following OHCA. Today, the only way to maximise neurological recovery is to lower the body temperature after hospital admission, even if the optimal target is still debated (between 32 and 36 °C). The severity of the reperfusion injury, which is dependent on the cause of arrest, pre-arrest condition, anoxia time, time to ROSC, and quality of CPR/ALS, should probably prompt different treatment options and not the ‘one size fits all’ strategy that we follow today. Novel cooling techniques will be able to provide ultrafast cooling, which has proven highly efficient in animal experiments, even intra-arrest, and this will perhaps provide us with more answers.

In 2050, it will also be possible to combine TTM with pharmacological neuroprotection, and, the use of inhaled noble gases (particularly xenon) is probably one of the most exciting ongoing research programs (15). Finally, early neuroprognostication will be facilitated by using a well-established algorithm combining clinical data, biomarkers, electrophysiology (continuous EEG and evoked potentials) and brain magnetic resonance imaging. Importantly, both timing and methods are crucial to avoid self-fulfilling prophecy (12).

Efficacy (explanatory) trials examine interventions under ideal and controlled circumstances and by using narrow inclusion criteria tend to involve relatively homogeneous populations. Effectiveness (pragmatic) trials evaluate interventions in real-life settings. The high mortality and the heterogeneity of cardiac arrest patients can make it challenging to demonstrate significant differences between control and intervention groups in effectiveness trials. This might be partly because most included patients already have irreversible neurological injury before randomisation and treatment allocation. In the future, new approaches to the design of clinical trials in resuscitation (e.g. adaptive trial design) may improve efficiency and produce more meaningful results.

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Table 1. Chain of survival in 2050

Early recognition and alert	Wireless biosensors in high-risk patients
	Widespread education of public
	Use of GPS systems
Defibrillation	Widespread deployment of AEDs
	AEDs delivery by drones
	Waveform analysis guided defibrillation
Advanced life support	Goal-directed resuscitation
	Ultrasound examination
	Fast ECPR in refractory cases
Post-resuscitation care	Better early diagnostic tools
	Ultrafast cooling
	Reliable prognostication

GPS: global positioning systems

AED: automated external defibrillators

ECPR: extra-corporeal resuscitation