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Réduire le délai de défibrillation des arrêts cardiaques extrahospitaliers : *une approche multimodale*

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Liste de publications et participations aux conférences

Liste des publications réalisées dans le cadre du projet de thèse :

1. Derkenne C, Jost D, Thabouillot O, et al. Improving Emergency Call Detection of Out-of-Hospital Cardiac Arrests in the Greater Paris Area: Efficiency of a Global System with a New Method of Detection. Resuscitation. 2020;146:34-42

2. Derkenne C, Jost D, Roquet F, et al. Mobile Smartphone Technology Is Associated With Out-Of-Hospital Cardiac Arrest Survival Improvement: The First Year "Greater Paris Fire Brigade" Experience. Acad Emerg Med 2020;27:951-962

3. Derkenne C, Jost D, Miron De L'espinay A, et al. Automatic external defibrillator provided by unmanned aerial vehicle (drone) in Greater Paris: a real world-based simulation. Resuscitation. 2021;162-259:265

4. Derkenne C, Frattini B, Menetre S, et al. Analysis During Chest Compressions in Out-Of-Hospital Cardiac Arrest Patients, A Before/After Study: The DEFI 2022 Study, soumis pour publication le 16 mars 2024 à *Circulation*

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1. Poster congrès Société Française de Médecine d'Urgence 2019 « Etude observationnelle validant une nouvelle procédure de détection téléphonique des arrêts cardiaques extrahospitaliers »

2. Audition parlementaire dans le cadre du projet de loi visant à lutter contre la mort subite et à sensibiliser la population aux gestes qui sauvent (2019)

3. Présentations orales aux « Jeudi de l'Urgence du Bataillon des Marins-Pompiers de Marseille » et aux « Conférences de médecine préhospitalière du Val-de-Grâce – BSPP » du travail sur les Bons Samaritains (2019, 2020, 2021)

4. Poster congrès Société Française de Médecine d'Urgence 2020 « Drone porteur de DSA en milieu urbain dense. Modélisation multiparamétrique complexe dynamique pour optimiser les choix »

5. Poster congrès Société Française de Médecine d'Urgence 2020 « Performance des médecins urgentistes préhospitaliers pour la reconnaissance d'un rythme électrique chocable en cas d'arrêt cardiaque »

6. Présentation orale congrès du Club des Anesthésistes Réanimateurs et Urgentistes Militaires 2021 « SIMUL-CHOC, quelle performance pour les urgentistes qui défibrillent ? »

7. Présentation orale congrès de la Société Française de Médecine d'Urgence 2023 « Analyse en continu par le défibrillateur »

8. Poster au congrès de l'American Heart Association 2023 "Heart Rhythm Analysis During Chest Compressions in Case of Out-of-Hospital Cardiac Arrest: Are Confirmation Analysis a Safety Issue?" *(présentation par un autre membre de l'équipe de recherche)*

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Participations aux conférences et écoles d'été au cours de la période de thèse (septembre 2020 - juin 2024):

1. MOOC éthique de la recherche (2020)
2. MOOC intégrité scientifique (2021)
3. Congrès de la Société Française de Médecine d'Urgence 2020 et communication orale
4. Congrès de la Société Française de Médecine d'Urgence 2021 et communication orale + poster
5. Congrès de la Société Française d'Anesthésie Réanimation 2021 et 2 communications orales
6. Conférence de médecine préhospitalière du Bataillon des Marins-Pompiers de Marseille 2021 et communication orale
7. Formation nationale des Directeurs des Secours Médicaux (EHESP / EVDG / ENSOSP) 2021 et chargé de cours à cette formation depuis (4 occurrences)
8. Congrès de la Société Française de Médecine d'Urgence 2022 et communication orale + poster
9. Conférences préhospitalières de Médecine d'Urgence de l'Ecole du Val-de-Grâce et des Pompiers de Paris 2022 et 2 présentations orales
10. Congrès de la Société Française de Médecine d'Urgence 2023 et communication orale
11. Congrès cœur et sport 2023 et communication orale

Résumé

Délivrer rapidement un choc électrique à un myocarde qui fibrille est l'action la plus efficace pour faire cesser un arrêt cardiaque et rétablir une circulation efficace. Cette action simple en apparence cache de multiples complexités : il s'agit tout autant de dépister l'arrêt cardiaque au téléphone, de permettre à un défibrillateur d'arriver auprès du patient ou que le médecin ou le défibrillateur dépiste correctement les rythmes électriques des arrêts cardiaques.

Pour le dépistage des arrêts en centre d'appel téléphonique, l'algorithme de détection des arrêts cardiaques « top ventre » a permis de faire passer le taux de détection de 54 à 93% entre 2012 et 2018 et au taux de recherche d'un défibrillateur public par les témoins de 0 à 20%.

Pour l'accès au défibrillateur, le déploiement d'un système de citoyens sauveteurs capables d'initier le massage cardiaque et la défibrillation a permis en un an, à 52 « Bons Samaritains » d'aider à la prise en charge des patients. 18 ont pu apporter un défibrillateur qui a été utilisé avant l'arrivée des pompiers. L'action d'un Bon Samaritain était associée à une augmentation de la survie (OddRatio ajusté par rapport au groupe contrôle = 5,9 [95% CI = 2,1-16,5]. Dans une simulation numérique dans laquelle les casernes de pompier disposaient fictivement d'un drone porteur de DSA 72,2% des arrêts cardiaques simulés ne pouvaient pas disposer d'un drone : les conditions n'étaient pas réunies pour qu'il puisse voler. En revanche, dans 93% des cas où le drone pouvait voler, il arrivait avant le DSA apporté par les pompiers. Autoriser les drones simulés à voler pendant la nuit aéronautique était le paramètre de vol permettant de réduire le plus le temps d'accès au défibrillateur.

Pour la reconnaissance des rythmes électriques, 190 médecins urgentistes confrontés à des tracés cardioélectriques de patient en arrêt cardiaque sur un simulateur numérique présentaient une sensibilité pour délivrer des chocs pour les rythmes chocables de 1 [EIQ 1,0-1,0] mais une spécificité pour ne pas choquer les rythmes non chocables de 0,83 [EIQ 0,86-1,0]. Leur vitesse de décision était bien plus rapide que celle des défibrillateurs (2 à 3 secondes).

Enfin, pour une population de patients en arrêt cardiaque extra hospitalier et en fibrillation ventriculaire initiale, un nouvel algorithme de défibrillation a été utilisé par les pompiers de Paris. Il était capable d'analyser le rythme électrique pendant les compressions thoraciques et, en cas de dépistage de récidive de fibrillation, de réduire la phase de délivrance des compressions thoraciques pour provoquer une analyse anticipée. Son utilisation était associée à davantage de délivrance de compressions thoraciques (Chest Compression fraction passant de 72 à 77%) et à une réduction de moitié du temps passé en fibrillation ventriculaire. Dans une sous population de patients de cette étude (sur la voie publique, avec un délai d'arrivée du défibrillateur court) l'utilisation de cet algorithme était associée à un gain de survie (Hazard Ratio ajusté pour le décès 0.85 [EIQ 0.76–0.96]).

Mots clés : défibrillation, arrêt cardiaque extrahospitalier, drone, défibrillateur, expertise médicale, nouvelle technologie, centre de réception des appels.

Abstract

Rapid delivery of an electric shock to fibrillating myocardium is the most effective way of terminating cardiac arrest and restoring effective circulation. This apparently simple action involves many complexities: it is just as much a question of detecting cardiac arrest by telephone, allowing a defibrillator to reach the patient or ensuring that the doctor or defibrillator correctly detects the electrical rhythms of cardiac arrest.

For the detection of cardiac arrest, the "hand on belly" cardiac arrest detection algorithm used in telephone call centres has increased the detection rate from 54 to 93% between 2012 and 2018, and the rate of bystanders looking for a public defibrillator from 0 to 20%.

In terms of access to defibrillators, the implementation and deployment of a citizen rescuer system that can initiate cardiac massage and defibrillation enabled 52 "Good Samaritans" to help with patient care in one year. 18 were able to bring a defibrillator that was used before the fire brigade arrived. The action of a Good Samaritan was associated with an increase in survival (adjusted OddRatio compared with the control group = 5.9, [95% CI 2.12 to 16.54]. In a computer simulation in which the fire stations had a drone carrying an AED, in 72.2% of simulated cardiac arrests, the conditions were not right for the drone to fly; conversely, in 93% of cases where the drone was able to fly, it arrived before the AED brought by the firefighters. Allowing simulated drones to fly during the aeronautical night was the flight parameter that reduced the time taken to access the defibrillator the most.

For the recognition of electrical rhythms, on a digital simulator, 190 emergency physicians facing cardioelectric tracings of patients in cardiac arrest had a sensitivity for delivering shocks for shockable rhythms of 1 [IQR 1.0-1.0] but a specificity for not shocking non-shockable rhythms of 0.83 [IQR0.86-1.0]. Their decision speed was much faster than that of defibrillators (2 to 3 seconds).

Finally, for a population of out-of-hospital cardiac arrest patients with initial ventricular fibrillation, a new defibrillation algorithm was used by the Paris fire brigade. It was designed to analyse the electrical rhythm during chest compressions and, in the event of detection of recurrence of fibrillation, to reduce the phase of delivery of chest compressions in order to initiate an early analysis. Its use was associated with an increase in the delivery of chest compressions (Chest Compression fraction rising from 72 to 77%) and a halving of the time spent in ventricular fibrillation. In a sub-population of patients in this study (on the public highway, with a short delay in the arrival of the defibrillator) the use of this algorithm was associated with a gain in survival (adjusted hazard ratio for death 0.85 [EIQ 0.76-0.96]).

Key words: defibrillation, out-of-hospital cardiac arrest, drone, defibrillator, medical expertise, new technology, emergency response centre.

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Je ne cite pas nommément ceux qui n'ont pas apporté de contribution directe à ce travail, mais nombre l'ont rendu possible, qu'ils en soient remerciés !

Affidavit *3*

Affidavit *4*

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INTRODUCTION

La plupart des écrits scientifiques sur l'arrêt cardiaque (AC) commencent par rappeler ces chiffres : presque 400 000 arrêts cardiaque extrahospitaliers se produisent chaque année aux Etats-Unis, 46 000 en France. Leur survie n'excède pas 10% des patients, et 20% des survivants présentent une altération majeure des capacités relationnelles. Si ces données épidémiologiques sont une introduction quasi constante c'est qu'elles illustrent tout à la fois une incidence élevée et un pronostic très sombre.

La prise en charge des patients en AC pourrait presque se résumer à deux gestes : comprimer le thorax et défibriller. Ces deux actions sont celles qui disposent du plus haut niveau de preuve scientifique. A elles deux, elles conditionnent quasi totalement le pronostic des patients. Et pourtant, cette apparente simplicité se heurte à une grande complexité. Non seulement, chacun de ces deux gestes pose d'innombrables questions - techniquement seulement partiellement résolues - mais surtout, elles requièrent une très bonne articulation d'intervenants extrêmement variés. La survie dépend de témoins rarement formés au secourisme, de centres d'appels qui doivent identifier au téléphone des patients en arrêt cardiaque qui représentent moins d'1% de leurs appels, de secours non médicaux et enfin des secours médicaux.

Défibriller, c'est à dire délivrer un courant électrique à travers la poitrine d'un patient est le geste le plus à même de restaurer une activité cardiaque électrique compatible avec un pouls, nous nous en justifierons ci-après. La plus grande partie de son efficacité provient de la capacité des systèmes de soins à réaliser cette défibrillation dans un délai le plus court possible après l'effondrement du patient. Cette contrainte absolue est une gageure, puisque désormais tous les intervenants peuvent réaliser cette défibrillation, mais qu'il ne semble pas exister de solution univoque pour tous les patients.

Ce manuscrit, après une première partie consacrée à des rappels fondamentaux, présente quatre études scientifiques publiées et une en phase de soumission, qui s'intéressent aux différents maillons de la chaîne de survie, pour réfléchir comment chacun peut réduire son délai de défibrillation. Non pas chronologiquement, mais suivant leur ordre dans la chaîne de survie, nous rapportons ainsi les résultats d'une étude en centre de réception des appels d'urgence où la défibrillation guidée par téléphone est encore relativement confidentielle. Nous avons ensuite développé et fait maturer un système utilisant des citoyens sauveteurs pour masser et défibriller jusqu'à obtenir de premiers résultats. Par la suite, nous nous sommes intéressés à la performance simulée et attendue d'un drone porteur de défibrillateur en zone urbaine très dense. Ensuite, nous avons analysé les premiers résultats cliniques de la mise en place d'un algorithme

de défibrillation, permettant à un défibrillateur semi-automatique d'analyser le tracé électrocardiographique pendant les compressions thoraciques pour réduire le délai de refibrillation. Enfin, nous avons étudié la performance de médecins préhospitaliers pour identifier un rythme chocable sur un défibrillateur manuel.

1. DONNEES FONDAMENTALES

1.1. ARRET CARDIAQUE : DEFINITION ET RYTHMES ELECTRIQUES

1.1.1. De l'arrêt cardio respiratoire non défini à l'arrêt cardio respiratoire sans arrêt complet cardiaque et respiratoire : une histoire moderne des AC

L'histoire médicale récente des arrêts cardiaques débute par des recommandations thérapeutiques, assez curieusement sans indication précise. C'est ainsi qu'en novembre 1958, une conférence américaine reconnaît le bouche à bouche comme une technique de réanimation des patients apnéiques. En 1960, l'adjonction de compressions thoraciques à la ventilation est reconnue comme capable de rétablir un pouls palpable, et se répand dans la communauté médicale (1). L'arrêt cardiaque n'est, alors, pas clairement défini.

En 1966, sont publiées les premières recommandations internationales sur l'arrêt cardiaque : elles affirment que la reconnaissance d'un arrêt cardiaque associe une inconscience, une respiration anormale et une absence de pouls palpable. Elles proposent de former aux compressions thoraciques et à la ventilation tout soignant et secouriste professionnel (2). Les recommandations suivantes, en 1974, étendent cette recommandation au grand public (3). Elles ont, par la suite, connu des révisions périodiques en 1980, 1986, 1992, 2000, 2005, 2010, 2015, 2019 - spécialement dédiée au SARS-COV-2 – 2021 et 2023. Les recommandations citées ici sont celles de l'*American Heart Association*. Il existe également des recommandations européennes depuis 1992, (*European Ressuscitation Council*) qui sont presque toujours concordantes, puisque toutes découlent des recommandations de *l'International Liaison Comittee On Ressuscitation* (ILCOR) (4). La méthode d'écriture des recommandations est basée sur une découpe question par question par une architecture PICO (Population / Intervention / Comparator / Outcome / Study designs / Timeframe) accessible en ligne (https://costr.ilcor.org/).

Il est remarquable de noter que, dès 1966, le diagnostic d'arrêt cardiaque n'impose pas l'absence totale de ventilation, puisque la présence de gasps (respiration agonique) est déjà assimilée à un signe positif d'arrêt cardiaque. Il s'agit d'Arrêt Cardiaque (AC), davantage que d'Arrêt Cardio-Respiratoire (ACR). Il faut, à l'inverse, attendre 2015 pour que les convulsions puissent être considérées comme un des premiers signes d'AC et que l'association « convulsion et respiration irrégulière » indique des compressions thoraciques (5,6).

La vérification d'un pouls palpable est abandonnée pour le grand public en 2000 (7), en raison de plusieurs études apportant la preuve de la difficulté dans sa recherche (8,9). La définition des AC évolue alors pour être définie comme l'association d'une inconscience et

d'une ventilation anormale. Depuis 2021, cette définition est pratiquement identique pour les équipes médicales, puisque la recherche du pouls n'y est permise que simultanément à l'évaluation de la respiration, et uniquement pour les équipes expérimentées (10).

La notion de rythme électrique n'apparaît donc pas dans la définition actuelle d'arrêt cardiaque. Il est également accepté que soient considérés comme en arrêt cardiaque des patients qui pourraient avoir un pouls, le rapport bénéfice risque de compressions thoraciques par excès restant très favorable (recommandation de grade 1) (11–13) (voir 1.3.3.1). De même, il peut exister, chez un patient inconscient avec respiration anormale, une alternance de périodes avec et sans activité cardiaque mécanique. Les périodes avec activité mécanique mais sans pouls palpable sont alors constitutives d'une insuffisance circulatoire aigüe et requièrent des compressions thoraciques (cas des fausses dissociations électro-mécaniques, voire 1.1.3) (14).

La défibrillation a été réalisée une première fois en 1947 sur un patient au décours d'une chirurgie cardiaque, avant de devenir possible « à thorax fermé », puis de devenir mobile et donc extrahospitalière, avant de se démocratiser à partir des années 1980 (voir fig 1).

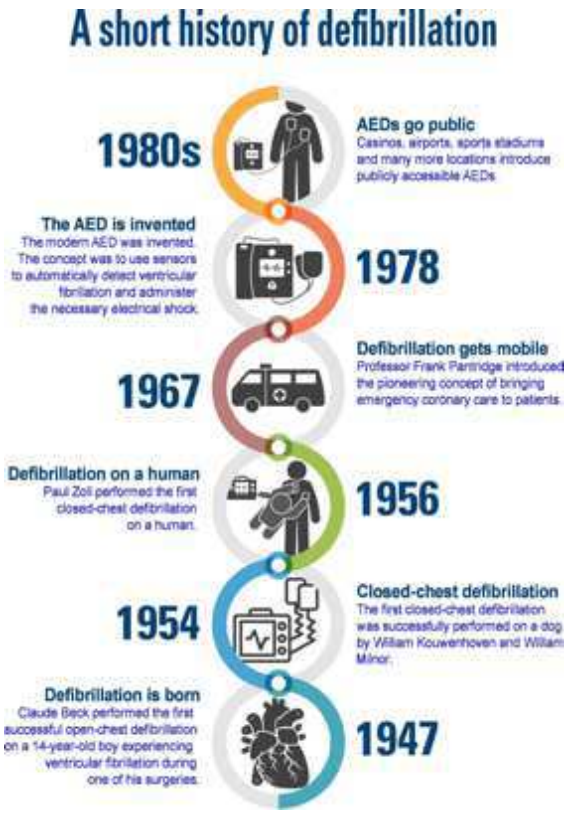

Figure 1: Histoire de la défibrillation selon Brools et al (15).

La définition des patients en AC a donc évolué pour accepter un très léger sur-triage, mettant ainsi en balance d'un côté, la gravité absolue d'un éventuel retard à l'instauration d'un traitement, avec, de l'autre, le très faible risque de traiter par excès des patients qui n'auraient pas, *stricto sensu*, d'arrêt total de la fonction cardiaque et pulmonaire. Ces dernières affirmations sont vraies chez les patients en AC extrahospitalier qui sont la population étudiée par notre travail, mais moins chez les patients intra hospitaliers (pour ceux bénéficiant de la mesure continue invasive de la pression artérielle tout du moins).

1.1.2. Épidémiologie et étiologie

Par le terme d'AC, l'American Heart Association s'intéresse aux « *unexepected cardiovascular collapse* », excluant, *de facto*, les AC prévisibles de fin de vie et ceux traumatiques (16). Les AC recouvrent des situations cliniques très distinctes, en incidence, présentation clinique, données paracliniques et pronostiques. Si la classification des AC est parfois aisée, de très nombreuses variabilités dans les modalités d'enregistrement dans les bases de données régionales et nationales doivent rendre précautionneuse l'utilisation de données chiffrées, malgré l'utilisation courante du modèle d'Utstein (17–19). Par exemple, la survie après un AC est rapportée entre 1,8 et 94,3% selon les pays (17). Enfin, les étiologies d'arrêt cardiaque médicales sont très régulièrement présomptives, souvent portées *a posteriori*, et avec un biais du survivant quasiment constant. Par exemple, il peut être difficile de distinguer les lésions coronaires responsables d'arrêt cardiaque d'autres, chroniques et non coupables ; il est parfois malaisé de distinguer les patients ayant une hémorragie cérébrale après une chute provoquée par l'AC de ceux pour lesquels cette hémorragie est l'étiologie de l'AC ; une part non négligeable d'AC est d'étiologie inconnue (20,21).

On distingue tout d'abord les arrêts cardiaques intra et extra hospitaliers. Pour les premiers, l'incidence varie de 1 à 6 pour 1 000 admissions dans les pays occidentaux, avec une survie de 10 à 25% (22,23). Pour les AC extrahospitaliers, l'incidence est, en Europe, de 37/100 000 habitants/an. En France, elle est rapportée à environ 60/100 000 adultes/an et 10/100 000 enfants/an, soit, environ, 46 000 AC/an. Seul environ un patient sur deux bénéficie d'une réanimation médicalisée (24–27).

En France, comme dans d'autres pays européens, les patients en AC extrahospitalier ont un sex-ratio H/F d'environ 2/1, avec un âge médian de 65 +/- 15 ans (21,25,28). Les deux tiers des AC extrahospitaliers ont lieu à domicile, le reste étant le plus souvent sur la voie et dans les lieux publics, et quelques pourcents au travail. Le taux d'AC devant témoin est, dans les études,

très variable, de 50 à 80%, de même que le taux de compressions thoraciques entreprises avant l'arrivée des secours (30 à 70%). Lors de l'appel aux services d'urgence, l'AC est diagnostiqué par les opérateurs de manière très inégale selon les centres et selon les époques, de 0 à 90% (29–32). Les patients réanimés (environ 50-70% des patients pour lesquels un SMUR est dépêché, en France) sont, de 80 à 90% des AC d'origine médicale dont la moitié ou les deux tiers environ d'AC d'étiologie cardiaque présumée.

Les étiologies cardiaques d'arrêt cardiaque sont, lorsqu'elles sont retrouvées, à 80% ischémiques (syndrome coronarien aigu, ischémie chronique sans occlusion, spasme…), à 10% structurales (cardiomyopathies dilatées, valvulaires, hypertrophiques, congénitales, infectieuses, de stress…) et à 10% électriques (trouble de la conduction, Brugada, QT long, repolarisation précoce, Wolff Parkinson White…) (21,24,33).

Les étiologies médicales non cardiaques regroupent classiquement l'hypoxie quelle qu'en soit la cause, l'embolie pulmonaire, les hypovolémies absolues ou relatives, les dyskaliémies et autres troubles électrolytiques, et encore d'autres causes, plus rares.

1.1.3. Rythmes électriques d'arrêt cardiaque

Les rythmes électriques des AC peuvent être classés selon que l'administration d'un choc électrique sur ces rythmes est susceptible, ou non, de permettre une Reprise d'Activité Circulatoire Spontanée (RACS) (Fig 2). Sont considérées comme chocables (34) :

- les fibrillations ventriculaires à larges mailles (*Coarse Ventricular Fibrillation – coarse VF* ; absence d'activité électrique organisée, trémulation de la ligne de base avec amplitude pic à pic > 200 µV) ;
- les tachycardies ventriculaires « rapides » (*Ventricular Tachycardia (VT)).* L'appréciation de la fréquence « rapide » est laissée à l'appréciation des constructeurs de défibrillateurs (>160-170/min le plus souvent) (34).

Sont considérées comme non chocables :

- les asystolies (ligne de base plate ou trémulation de la ligne de basse amplitude avec pic à pic <100 µV)
- les dissociations électro-mécaniques (*Pulsless Electrical Activity – PEA*). Ces dernières sont définies comme la persistance d'une activité électrique organisée sans pouls palpable. On peut distinguer les *falses PEA* (persistance d'une activité mécanique cardiaque synchrone de l'activité électrique mais insuffisante pour générer une onde de pouls à 50mmHg, palpable en carotidien ; souvent à QRS de morphologie fine et/ou

conservée et avec ondes P présentes ; de pronostic médiocre ; parfois appelées « *pseudo PEA* »), des *true PEA* (absence totale d'activité mécanique cardiaque malgré persistances d'activité électrique, souvent à QRS très dégradés, larges, sans onde P et à très mauvais pronostic). Usuellement, une PEA avec des QRS moins fréquents que 6-10/min est classée comme asystolie.

Enfin, une classe de rythmes dont la chocabilité est incertaine est nommée « intermédiaire ». L'application d'un choc électrique permet parfois d'obtenir leur résolution, mais de manière inconstante, et avec des chances d'obtenir un rythme électrique organisé assez faible. On y retrouve :

- les VT plus lentes que 160/min
- la VF fine, c'est à dire entre 100 et 200 µV pic à pic

Enfin, la littérature ne décrit pas les périodes de transition des rythmes électriques entre eux, quand bien même elles se produisent pendant la période d'analyse d'une réanimation cardiopulmonaire. Pour un défibrillateur qui analyse un segment électrique donné, il n'existe aucune recommandation de délivrance ou non d'un choc quelle que soit la proportion ou le l'ordre d'enchainement entre un tracé chocable et non chocable.

TABLE 1. Rhythm Categories — A

Shockable rhythms (require high sensitivity of arrhythmia analysis algorithms in the absence of artifacts):
Coarse VF (peak-to-peak amplitude >200 µV [AAMI DF39] or other criteria specified in detail by manufacturer)
Rapid VT (criteria specified in detail by manufacturer)*
Nonshockable rhythms (require high specificity of arrhythmia analysis algorithms):
Normal sinus rhythm
Supraventricular tachycardia (includes sinus tachycardia, bundle branch block, WPW syndrome)
Sinus bradycardia
Premature ventricular contractions
Atrial fibrillation, with or without bundle branch block
Atrial flutter
Second- or third-degree heart block
Idioventricular rhythms
Asystole—for safety and according to AHA Guidelines for CPR and ECC.† Manufacturer should specify amplitude criteria separating fine VF and asystole.
Intermediate rhythms (report sensitivity or specificity of arrhythmia analysis algorithms):
Low-amplitude, low-frequency (fine) VF (ie, does not meet definitions of coarse VF above)
Other VT (ie, does not meet criteria for VT in the shockable rhythms category above)

VF indicates ventricular fibrillation; AAMI, Association for the Advancement of Medical Instrumentation; VT, ventricular tachycardia; WPW, Wolff-Parkinson-White syndrome.
*The task force did not specify a minimum rate above which VT should be shocked, because tolerance for VT varies widely among patients. Each manufacturer should specify criteria for VT used in its algorithm.

	Rapid rate ± P waves	Slow rate, no P waves
Narrow QRS	• Hypovolemia, including trauma/bleeding • Septic/anaphylactic shock • Cardiac tamponade • Pulmonary embolism (usually) • Tension pneumothorax • Dynamic hyperinflation • Cardiogenic shock (variable) • Any other cause of profound shock	• Massive inferior MI (P waves with complete heart block) • Vagal response due to pulmonary embolism or other obstructive shock • Hypothermia (variable)
Wide QRS	• Massive anterior MI • Pulmonary embolism (rarely, in presence of acute RBBB) • Tricyclic antidepressant overdose ± other sodium channel blocker overdoses	• Hyperkalemia • Hypoxemia • Acidosis • Postcountershock PEA • Hypothermia (variable) • Sodium-channel blocker overdose (variable)

B

Figure 2 : Classification des rythmes d'AC (panel A, selon Kerber et al. (34)) ; Étiologies des dissociations électromécaniques (panel B, selon Jentzer et al. (14))

1.1.4. Limites de la classification des rythmes électriques

Dans les études, l'identification des rythmes d'AC s'appuie sur la relecture de tracés de défibrillateurs. Ces tracés peuvent se trouver illisibles (35), et des artéfacts (induits par le massage, la ventilation etc.) peuvent parasiter l'analyse. De plus, il existe de manière constante

une autre limite : une seule dérivation est analysable. Elle correspond, grossièrement au dII des électrocardiogrammes (ECG) , mais la position des électrodes est souvent imprécise, cependant que leur taille est bien supérieure à la taille d'une électrode d'ECG (voir 1.4.1.1.). Si la distinction « chocable/non chocable » est souvent aisée, l'identification exacte du rythme sous-jacent n'est pas toujours possible. De même, certains tracés de DSA ne présentent pas la ligne d'impédance, pourtant utile à l'identification de mouvements respiratoires du patient (spontanés ou sous respirateur), de mouvements du patient (spontanés ou résultant de compressions thoraciques), et même d'activité mécanique cardiaque. Pour ce dernier, la présence d'une petite onde d'impédance, synchrone d'un QRS compatible avec un pouls a été décrite comme générée par les mouvements des battements cardiaques (36,37).

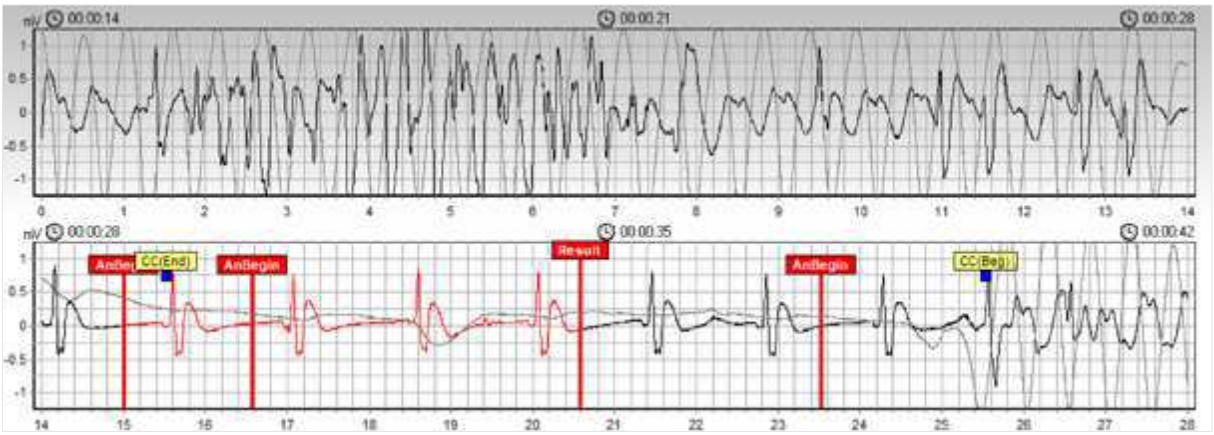

Figure 3 : Exemple de tracé de défibrillateur : une seule dérivation est analysable. Ici le rythme analysé (en rouge) est aisément identifiable comme non chocable. Cependant, affirmer qu'il s'agit d'un rythme sinusal est difficile, en l'absence d'onde P formellement identifiable, même pour ce rythme régulier à 60/min, à QRS fins. Les artefacts de la ligne électrocardiographique (noire) induits par le massage sont clairement visibles avant et après la période d'analyse ; la ligne d'impédance thoracique (grise) aide à distinguer ces périodes. Tracé issu du travail présenté en 3.4.

1.1.5. Facteurs associés aux rythmes électriques

De nombreux déterminants influencent le rythme électrique des patients en AC, rendant impossible l'association formelle d'un rythme électrique avec n'importe quelle autre variable (dont l'étiologie). Sont ainsi associés aux rythmes électriques des AC :

- le substrat histologique myocardique (très dépendant de l'âge du patient, des comorbidités ayant pu influencer sur son myocarde, ses coronaires, ses capacités conductives, contractiles, ou son automaticité etc.) (38,39);
- le trigger arythmogène éventuel de l'étiologie de l'AC. La fibrillation est majoritairement en rapport avec l'étiologie coronarienne, sans être exclusive (autres cardiomyopathies dont hypertrophiques, électrocution, hypokalémie, médicaments allongeant le QT etc.) (40,41). A l'inverse, les traumatismes, les hypoxies ne présentent pas, usuellement, de fibrillation spontanée (42). La figure 2 met en rapport différents aspects de PEA et l'étiologie présumée (14) ;
- les gestes effectués ou non avant l'observation du rythme (compressions thoraciques, défibrillation), les médicaments administrés ;
- le délai entre l'effondrement et le moment où ce rythme peut être observé.

Au sein des sociétés, l'ensemble de ces facteurs connaît des évolutions dans le temps : il a déjà été noté une diminution de la proportion de patients en *coarse VF* à l'arrivée des secours dans certains systèmes de santé, sans qu'il ne soit aisé de distinguer une cause unique : davantage d'étiologies non coronariennes ? Augmentation du délai d'arrivée des secours ? Diminution de la proportion de patients recevant des compressions thoraciques avant l'arrivée des secours ? Bien que cela puisse sembler paradoxal, une baisse de proportion des patients en VF à l'arrivée des secours s'était alors accompagnée d'une augmentation de la survie globale (VF passant de 33 à 26% pour une survie évoluant de 12,7% à 22,3% (43)).

1.1.6. Histoire naturelle des rythmes électriques

Pour les PEA, *true ou false*, l'étiologie initiale peut être différente, cependant la *true PEA* est également l'aboutissement de l'histoire naturelle d'une *false PEA* en l'absence d'obtention de RACS (fig 2) (14,44). Les PEA évoluent donc avec un élargissement progressif et une raréfaction des QRS.

Le plus souvent, en l'absence de compressions thoraciques, une *coarse VF* va voir ses mailles diminuer d'amplitude, devenir *fine VF* jusqu'à atteindre une asystolie (même si d'exceptionnelles réductions spontanées de VF pour devenir PEA sont possibles) (42). La réalisation de compressions thoraciques permet de ralentir cette évolution naturelle d'un facteur 2 ou 3.

En l'absence de compressions thoraciques ou d'administration médicamenteuse, les asystolies sont habituellement persistantes. Dans certains cas particuliers (hypothermie profonde en particulier) des bradycardies très sévères peuvent persister plusieurs heures, mimant une asystolie.

Certains travaux ont étudié finement l'organisation temporelle et les différents scenarii de succession des différents rythmes. Par exemple, il existe une réelle possibilité de RACS après une asystole, elle-même suivant une PEA, mais l'occurrence est beaucoup plus faible que si l'ordre est asystole puis PEA puis RACS (45,46) (Fig 4).

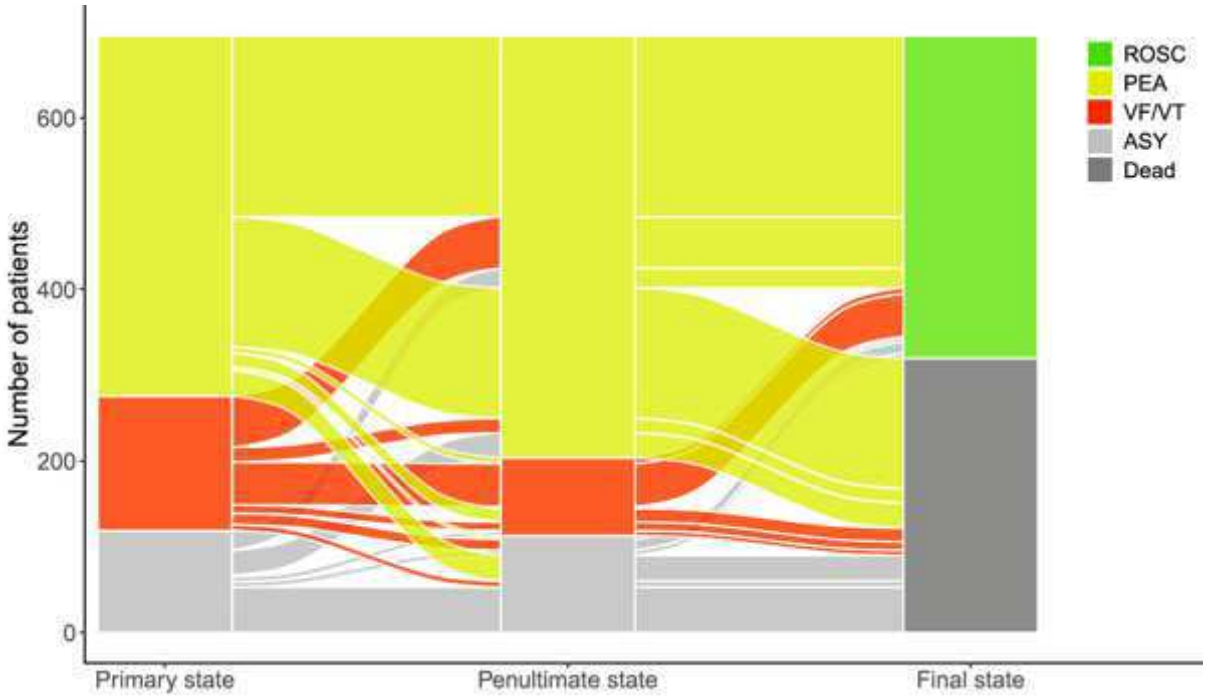

Figure 4: Diagramme de Sankey d'évolution des différents rythmes cardio électriques (pour des arrêts cardiaques intrahospitaliers) selon Norvik et al (45).

1.1.7. Fibrillation récidivante, réfractaire

A la suite immédiate de l'application d'un choc électrique sur une *coarse VF*, il est possible d'observer tous les rythmes. Une résolution de la VF peut être notée, avec récupération d'un rythme compatible avec un pouls palpable (RACS), parfois au prix d'une asystolie ou d'une *false PEA* temporaire (47).

Une récidive de VF peut être notée après une période sans VF (que celle-ci comporte ou non, un rythme organisé). Cette récidive peut être qualifiée de précoce, dans les 2 minutes qui suivent le choc, ou de tardive si elle intervient plus tard dans la prise en charge du patient. Le taux de récidive de VF et sa précocité sont extrêmement variables, en raison d'associations statistiques fortes avec l'âge du patient, la précocité de reprise des compressions thoraciques après le choc, le délai effondrement - choc et la période d'observation du rythme électrique. La littérature indique des récidives pour 20 et 80% des patients : parfois 50% de récidive dans les 2 premières minutes, ailleurs 70 à 90% de récidive dans la première minute suivant le choc (48–53). De manière tout à fait intéressante, nous disposons de données sur une cohorte parisienne très récente (2017) : la refibrillation se produit en moyenne 25 secondes après le choc [espace interquartile 13-44 secondes] (48).

Enfin, un certain nombre de VF choquées ne montrent aucune modification électrocardiographique, la VF est alors nommée persistante ou réfractaire.

1.1.8. Les trois phases de l'arrêt cardiaque

En 2002, un argumentaire pour une description des AC en trois phases successives est publié par Weisfeldt et al. (54).

Les 4 premières minutes de l'AC suivant l'effondrement sont rapportées comme la *« phase électrique »,* celle où l'administration d'un choc électrique sur un rythme chocable offre le maximum de produire une RACS (voir 1.4.4.1).

La phase de la 4ème à 10ème minute est nommée *circulatoire*. Il y est décrit que la défibrillation n'y est efficace que précédée d'un temps de compressions thoraciques. Ceci est tout d'abord retrouvé sur des modèles animaux. Par exemple : après 7 minutes sans compressions thoraciques chez des cochons en VF permanente, reprise des compressions puis défibrillation : le taux de RACS est inversement corrélé à une durée de pause pré-choc prédéterminée : 100% de RACS avec 3 secondes de pause pré-choc, 80% avec 10 secondes, 40% avec 15 secondes et 0% avec 20 secondes (55). Des études cliniques, qui restent de faible envergure et non complètement concluantes, étayent cette hypothèse. Lu et al. retrouvent une défibrillation d'autant plus efficace qu'elle est précédée de 90 secondes de compressions thoraciques après la 3ème minute post effondrement (56) ; Wik et al., dans une analyse en sous-groupe, rapportent une meilleur survie pour les AC de plus de 5 minutes post effondrement s'ils sont défibrillés avec 3 minutes de compressions thoraciques préalables (57). D'autre études

associent une durée préchoc courte et la probabilité d'une RACS (58,59). La nécessité de rétablir une perfusion coronaire avant l'administration d'un choc est évoquée.

La phase au-delà de 10 minute est la phase métabolique : il existe un retentissement de l'ischémie avec une part de mort cellulaire importante des organes nobles (dont l'endothélium), des troubles ioniques, une inflammation. Cette phase a donné lieu à de nombreux essais de cyto-protecteurs dont l'hypothermie : aucun n'est actuellement prouvé comme efficace.

Cette description est très efficace pour décortiquer assez finement la physiopathologie évolutive de l'AC et ses implications thérapeutiques successives. En revanche, comme l'admet l'auteur lui-même, en pratique clinique il est exceptionnel de pouvoir quantifier exactement le no flow. Par conséquent, la distinction entre les deux premières phases est impossible en pratique. Ceci, conjugué à l'absence de preuve clinique forte pour le massage préalable à la défibrillation, a conduit les recommandations à proposer d'utiliser les défibrillateurs dès que cela est possible, sans compressions thoraciques obligatoire préalable (60).

1.2. PRONOSTIC

Certains paramètres de bons pronostics dépendent de caractéristiques du patient : un âge jeune (61,62), une absence de comorbidité (62–64), une étiologie de l'AC curable ou cardiaque (21,65). Un nombre important de variables de bon pronostic sont liées au maintien d'une circulation minimale efficace *per AC*, par la réalisation de compressions thoraciques. Celles-ci permettent un débit sanguin minimal, laissant espérer une ischémie cérébrale et myocardique moindre et, *in fine*, le maintien prolongé d'une fibrillation ventriculaire, à même d'être résolue par un choc électrique pour obtenir une RACS (66,67). Sont ainsi de meilleur pronostic (62,63,68) :

- un effondrement devant témoin (*a fortiori* devant les secours) et par conséquent au travail ou sur la voie publique (61,69–72) ;
- un dépistage téléphonique efficace de l'arrêt cardiaque par les secours (73–77) ;
- la réalisation de compressions thoraciques par les témoins, spontanément ou de manière guidée (21,28,77,78) ;
- l'utilisation d'un défibrillateur avant l'arrivée des secours et/ou d'un premier rythme électrique chocable (21,25,28,61,65,69,79,80) ;
- une réanimation cardio-pulmonaire de haute qualité (68,81) ;
- un délai d'arrivée rapide des secours, et une forte densité en ambulance sur le secteur (25,69,78) ;

- une équipe médicale de haute performance et expérimentée (81–83).

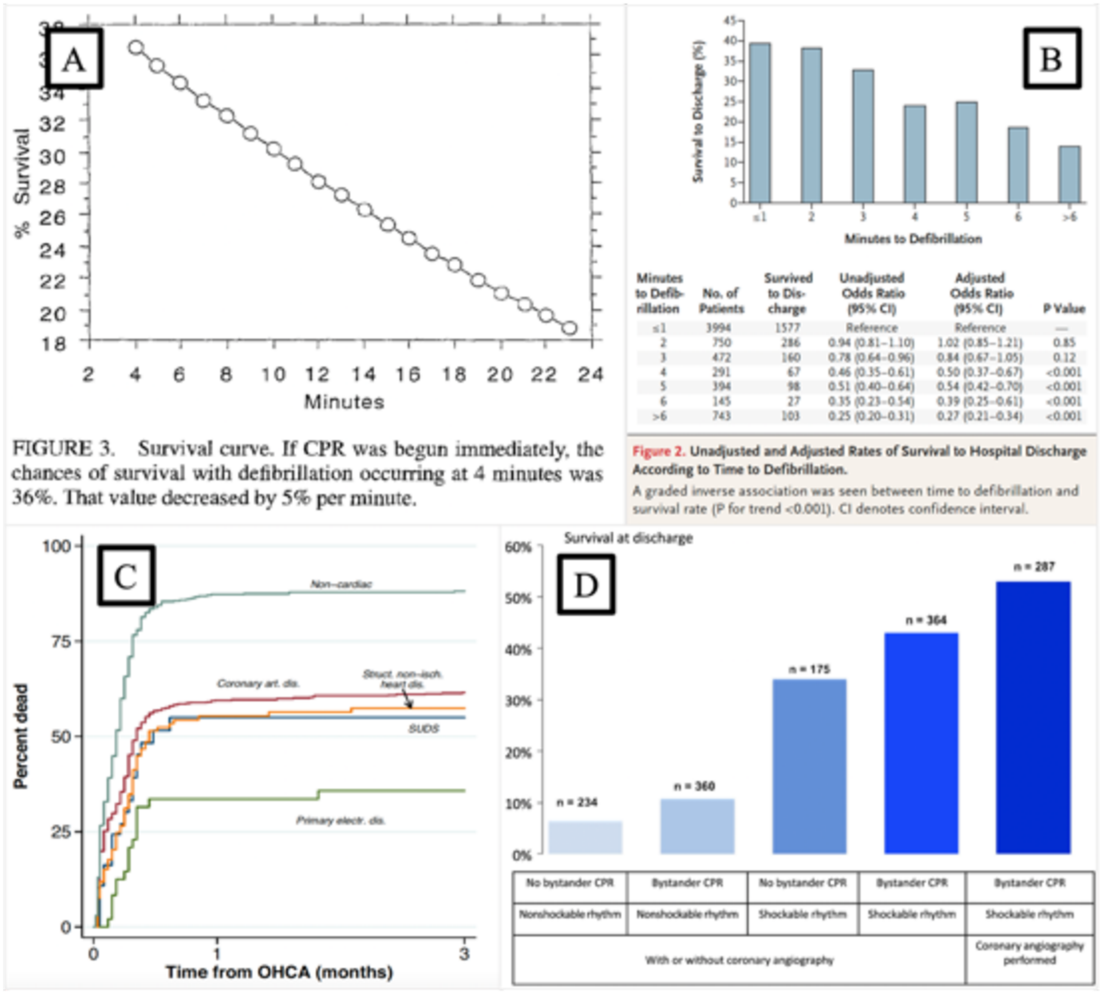

Figure 5 Facteurs explicatifs de la survie des AC extrahospitaliers. La mise en place de compressions thoraciques (panel A, selon Karch et al. (84)), la précocité de la défibrillation (panel B, selon Chan et al. (80)), l'étiologie cardiaque (panel C, selon Geri et al. (21)), et l'association de ces facteurs (panel D, selon Bougouin et al. (78))

Les variables pronostics les plus importantes sont la détection précoce, les compressions thoraciques précoces et la défibrillation précoce. Elles peuvent être, en partie, synthétisées par les variables *no-flow* (délai effondrement – début des compressions thoraciques) ou *low-flow* (délai début des compressions thoraciques – RACS) (85). Une vision simpliste sans être totalement erronée, basée sur deux publications historiques rapporte que le taux de survie des patients en AC diminue, à partir de l'effondrement, de 10% par minute sans compressions thoraciques (86), et de 5% lorsque le patient reçoit des compressions thoraciques (84). L'association des variables pronostic scelle la survie du patient.

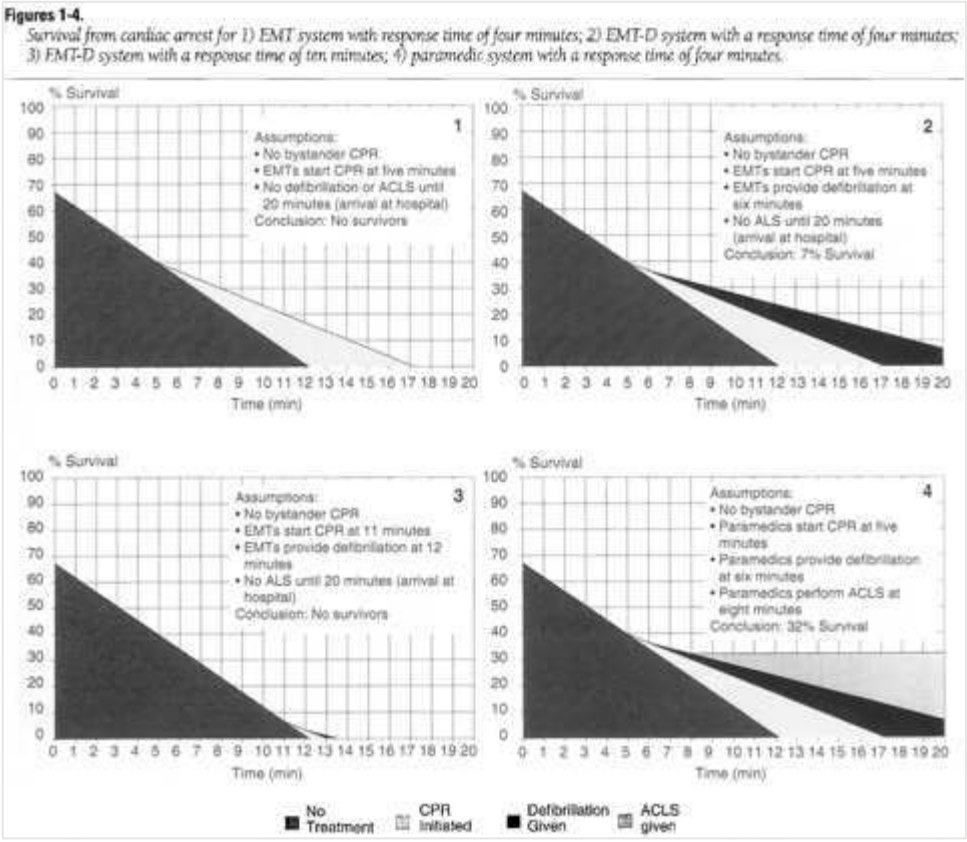

Figure 6 : Association des variables de survie, modélisation d'après Larsen et al. (87)

A l'échelle de la France, seuls 6% des patients ont un premier rythme électrique chocable, avec une survie, tout rythme confondu, de 5%.

A Paris, en revanche, environ 25% des patients en AC bénéficiant d'une réanimation ont un premier rythme considéré comme chocable par le défibrillateur ; le taux de survie à la sortie de l'hôpital de ces derniers étant également de 25% (88). A l'inverse, les 75% de patients sans rythme chocable présentent une survie de 2,4%. La survie, tout rythme confondu est d'environ 7%. Dans le monde, la survie globale des AC extra hospitaliers est rapportée comme allant de 3 à 20% (24–28,89).

1.3. TRAITEMENT DES ARRETS CARDIAQUES A L'EXCEPTION DE LA DEFIBRILLATION

1.3.1. Concept de chaîne de survie

Décrite en 1991 pour la première fois (67), et dans sa forme actuelle depuis 2005 (90), la chaîne de survie de l'AC schématise le traitement des AC extrahospitaliers comme une série d'actions, chacune impérative, et dont celle qui sera réalisée le moins efficacement détermine la survie du patient. Les maillons de cette chaîne, successifs dans le temps de prise en charge du patient, permettent à la fois d'identifier précisément et d'améliorer spécifiquement les variables associées à la survie des patients.

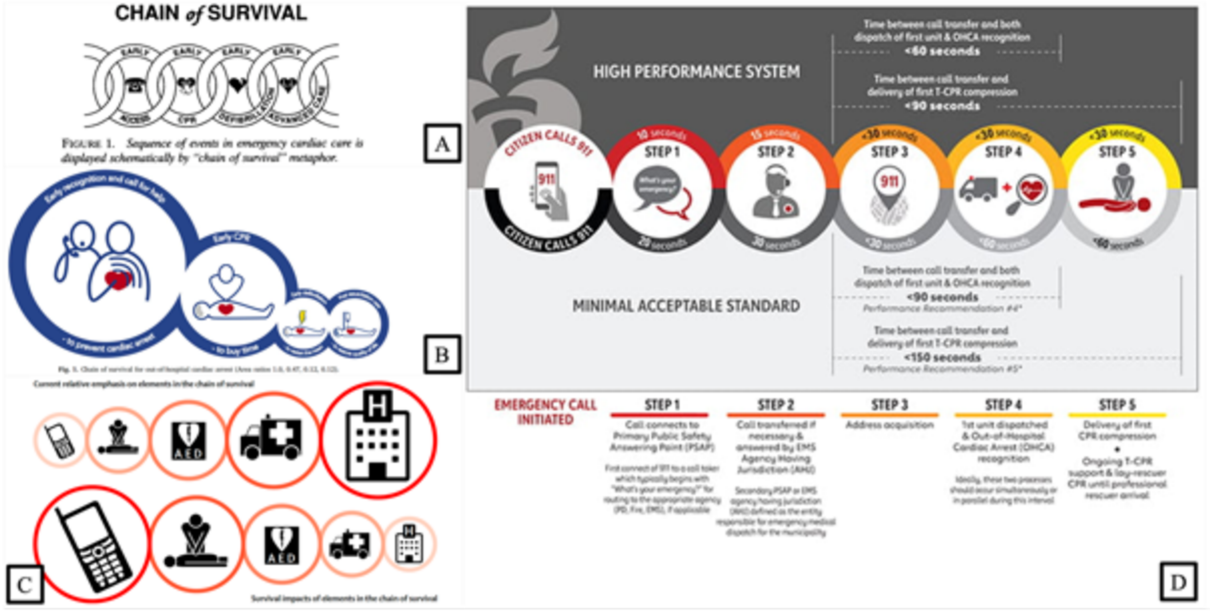

Figure 7 : Chaîne de survie originale (panel A, selon Cumins et al. (67) ; chaîne avec proportion de patients atteignant le maillon suivant (panel B, selon Deakins (88) ; chaîne avec importance relative de la recherche médicale et de l'impact sur la survie (panel C, selon Ong et al. (91)) ; chaîne de la gestion téléphonique des AC selon Christopher et al.(92))

De nombreuses versions de la chaîne de survie ont été décrites, pour des AC circonstanciels (noyés…), puis pour d'autres pathologies (traumatique, risque Nucléaire Radiologique Biologique Chimique) (93–95). Pour les AC présumés médicaux, Deakin a publié en 2018 une chaîne de survie dont les maillons sont proportionnels au nombre de patients atteignant le maillon suivant (88) ; une autre chaîne compare le poids respectif de chaque maillon sur la

survie des patients et la recherche scientifique qui y est dédiée (91). Ces deux publications mettent en exergue que la survie des patients est déterminée par la rapidité de la détection de l'AC, des compressions thoraciques et de la défibrillation.

Plus récemment encore est décrite une « cotte de maille » de survie (96). En effet, des systèmes de santé différents peuvent avoir des axes de progrès assez éloignés de la chaîne traditionnelle, assez occident-centrée (lutte pour l'accès à l'eau potable, accès à des dispositifs médicaux performants : des équipes médicales par exemple). De plus, certains maillons viennent bouleverser cette chaîne (drone-DSA, circulation extra-corporelle par exemple) en l'enrichissant voire en court-circuitant certains maillons.

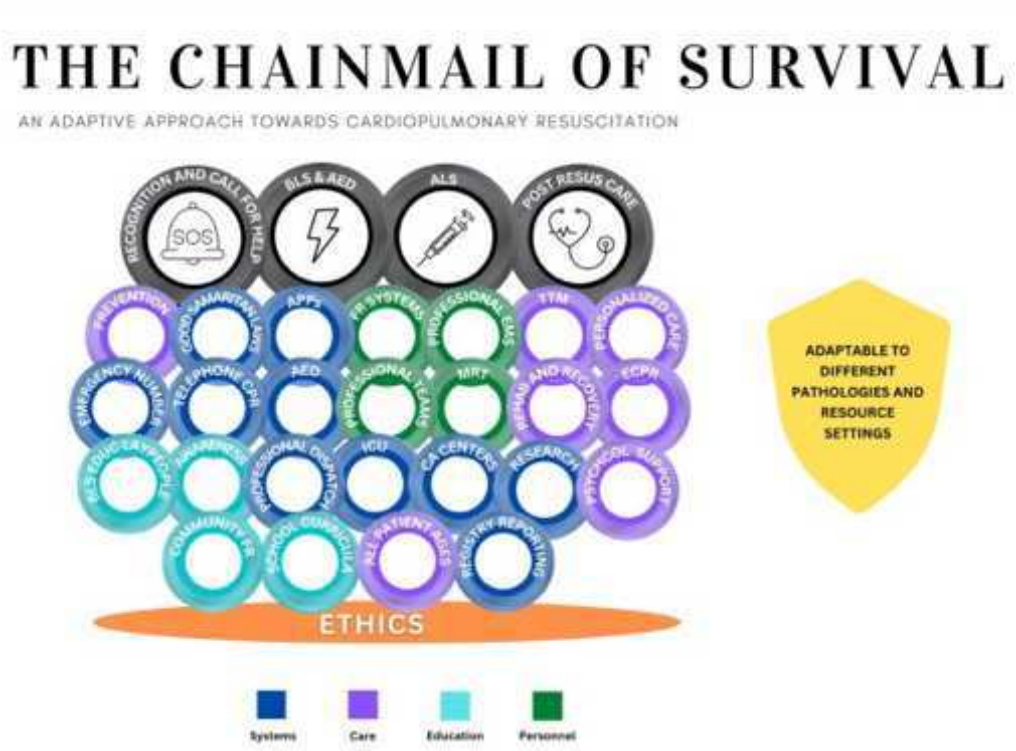

Figure 8: Cotte de maille des AC enrichissant la chaîne de survie de l'AC, augmentant sa compatibilité dans le temps et à travers les systèmes de santé selon Schnaubelt et al.

1.3.2. Dépistage de l'AC, t-CPR

Dans les recommandations de 1986, la reconnaissance de l'arrêt cardiaque s'appuyait sur les témoins, auxquels il était demandé d'appeler à l'aide un système d'urgence pour provoquer l'envoi des secours. Le centre de réception des appels, à peine évoqué, apparaissait comme un simple transmetteur d'alerte.

En 1991, dans la définition de la chaîne de survie, Cummins et al. définissent le premier maillon, « *early access link*», comme les actions spontanées des témoins (reconnaissance de l'AC, appel d'urgence, compressions thoraciques et bouche à bouche). Pour l'appel, deux difficultés majeures sont présentes : trouver un téléphone et identifier le bon numéro de téléphone. 85 différents numéros de téléphones d'alerte sont répertoriés dans certaines communautés et l'intérêt d'un numéro unique y est noté, ce dernier devant d'imposer, selon les auteurs, en Europe, dès 1992[1] (67). Un des points novateurs de ce manuscrit est que les auteurs identifient pour la première fois deux missions distinctes pour les centres d'appel : l'engagement rapide des moyens et le guidage des témoins pour la réalisation de compressions thoraciques. Dès cette époque, ces gestes guidés sont réputés efficaces même chez le témoin non formé (97); ils augmentent également la performance des témoins déjà formés (98). Le premier maillon de la chaîne unit donc les actions spontanées de témoins et les gestes réalisés grâce à un guidage : il s'agit du *telephon-Cardio Pulmonary Ressuscitation* (t-CPR).

Les recommandations internationales de 1992 reprennent ces données, proposent un délai d'une minute pour le délai décroché-envoi d'un véhicule de secours, et préconisent que tous les centres de réception des appels d'urgence puissent réaliser une t-CPR (99). Curieusement, encore une fois, les recommandations thérapeutiques devancent celles diagnostiques. Il faut attendre les recommandations de 2000 pour que la formation des opérateurs, l'utilisation d'algorithmes standardisés pour le guidage des compressions thoraciques continues sans bouche à bouche et l'utilisation d'un défibrillateurs y soit mentionnées (100). La méthode du NO *(conscience)* / NO *(respiration ou respiration anormale)* / GO *(initiez les compressions thoraciques)* est adoptée. En 2010, la mesure de la performance des opérateurs est reconnue comme un composant important des meilleurs programmes de gestion des AC (101). Les recommandations ajoutent enfin, en 2015, au trio « dépister, faire masser et faire utiliser un défibrillateur », l'utilisation des applications de citoyens sauveteurs pour aider à la réalisation des compressions thoraciques (102,103).

Depuis le début des années 2010, le centre d'appel 18/112 des pompiers de Paris utilise une technique novatrice pour dépister les AC (104). Ayant constaté que les AC les plus récents par rapport à l'appel (les plus à même de tirer bénéfice de compressions thoraciques et d'une défibrillation) présentaient souvent des gasps et que la question « le patient respire-t-il / respire-

[1] Le 112, numéro « unique » européen n'a été disponible qu'en 2000 et n'est pas, en 2022, un numéro d'alerte unique.

t-il normalement ? » était d'une grande difficulté pour des témoins souvent paniqués, la technique du « top ventre » a été développée. Elle est basée sur la recherche et la quantification des mouvements respiratoires chez les inconscients. Le témoin est invité à mettre sa main sur le ventre du patient et à dire « top » à chaque mouvement abdominal. En cas de mouvements espacés de plus de 7 secondes, des compressions thoraciques sont initiées. Les opérateurs téléphoniques sont encouragés à surtrier et à initier des compressions thoraciques au moindre doute (« objectif 140% de massage cardiaque ! »). Cette technique a autorisé une première hausse importante du nombre de patients en AC dépistés puis recevant des compressions thoraciques guidées au téléphone (104).

En 2018, malgré un demi-siècle d'effort de formation du grand public n'ayant pas permis de faire mieux que 50% de témoins capable de réaliser un massage cardiaque, et avec une hétérogénéité très importante entre les communautés, l'American Heart Association met à jour des recommandations spécifiques sur le t-CPR (92). La qualité du t-CPR des centres de réception d'alerte est effet un facteur indépendant de survie des patients :

- Bonne organisation via des centres d'appel à deux niveaux et des formations adaptées pour les opérateurs ;
- Bon dépistage via deux questions : « le patient est-il conscient ? Le patient respire-t-il normalement ? »
- Bons gestes : compressions thoraciques sans bouche à bouche (77); bonne fréquence de réalisation compressions thoraciques, insister sur leur profondeur ;
- Le critère le plus important de qualité est la mesure de la performance : taux d'AC dépistés; taux d'AC dépistés parmi les AC dépistables (sont exclus les AC déjà dépistés, les témoins non en présence de la victime etc.) ; taux d'AC dépistés réussissant à être guidés pour recevoir des compressions thoraciques ; et une série de délais parmi lesquels (délai première sonnerie – envoi des secours ; délai première sonnerie – dépistage AC ; délai première sonnerie – délivrance de la première compression thoracique par le témoin) (voir 3.1.)

Ces recommandations offrent pour la première fois des objectifs de délais extrêmement précis et ambitieux (figure 7). Cependant, la défibrillation par les témoins n'apparait ni dans les variables à monitorer, ni dans les objectifs chiffrés. De même, la cartographie des défibrillateur ni le guidage de pose des défibrillateur standardisés ne sont mentionnées (92).

1.3.3. Compressions thoraciques

1.3.3.1. Recommandations

Les recommandations actuelles sont de réaliser des compressions thoraciques dès le diagnostic d'AC, sans ventilation préalable (sauf pour les noyés, les enfants et les suspicions d'AC ayant comme étiologie une fausse route) (60). La technique recommandée est précise : les compressions thoraciques doivent être appliquées avec le talon d'une main, la seconde enveloppant la première, sur le tiers moyen ou inférieur du sternum, à une fréquence de 100-120/min, et à une profondeur de 5-6 cm (105). Le temps de compression doit être égal au temps de décompression. Le masseur doit veiller à opérer une décompression complète. Le patient est à plat dos ; une surface dure sous le patient contribue à un massage de qualité. Le masseur non expérimenté est requis de masser sans arrêt ; à deux, ils peuvent se relayer toutes les 2 minutes, ou moins, en cas de fatigue (60).

Toutes les interruptions de compression thoracique doivent être limitées au maximum : aucune reprise de pouls n'est autorisée en l'absence de monitorage du rythme cardiaque (ou de signes de vie majeurs, comme la parole), les défibrillateurs doivent être paramétrés et utilisés pour limiter au maximum les interruptions de massage (106). Les gestes médicaux (accès vasculaire, pose d'un dispositif de compression thoracique mécanique, intubation orotrachéale, échographie etc.) doivent être réalisés sans interruption du massage.

La quantité de compression thoracique, un de premiers objectifs d'une réanimation de qualité, est monitorée par la Chest-Compression fraction (*CCf*) qui se doit d'être la plus élevée possible, au-delà de 60% et idéalement vers 80% pour optimiser la survie (*CCf*= durée de compressions thoraciques/durée de l'arrêt cardiaque) (107,108) (voir critère de jugement principal de notre travail en 3.3.).

Les compressions thoraciques peuvent actuellement être également délivrées par des dispositifs mécaniques : bande de compression ou dispositif type piston. Ces massages cardiaques mécaniques n'ont jamais fait la preuve de leur supériorité par rapport à des secouristes performants, et ne sont pas recommandés en routine, à l'exception de situations où le massage prolongé peut être nécessaire (transport d'un patient hypotherme jusqu'à un dispositif de circulation extra corporelle par exemple) (109). Il existe, enfin, des dispositifs de compression alternant avec une décompression thoracique. Ils peuvent sembler plus efficaces que les compressions simples, associés aux valves d'impédance respiratoire dont la fonction est de bloquer l'entrée d'air par les voies aériennes supérieures lors de la phase de décompression. Il n'existe pas, là non plus, de recommandation d'utilisation de manière courante (110,111).

Les études comparant la défibrillation immédiate des AC ou la réalisation de compressions thoraciques préalablement à la défibrillation sont discordantes : certaines sont en faveur de compressions préalables (56,57), et d'autres sont non conclusives sur leur intérêt (112,113). En l'absence de preuve, il est actuellement recommandé de défibriller au plus tôt, pour les témoins, les secours non médicaux ou médicaux. Pragmatiquement, il est surtout recommandé de réaliser des compressions thoraciques le temps que la défibrillation puisse s'effectuer, ce qui représente, si le patient n'est pas déjà connecté à un défibrillateur, *a minima,* quelques minutes (114).

1.3.3.1. Compressions thoraciques et refibrillation

Il existe un lien entre compressions thoraciques et refibrillation ; les compressions thoraciques peuvent provoquer une capture ventriculaire, mécanique et électrique, à même de se produire en période réfractaire et d'initier une fibrillation (l'exemple le plus typique étant le *commotio cordis*) (115). Sur un myocarde hyperexcitable d'AC chocable, après la délivrance d'un choc électrique qui aurait permis la récupération d'un rythme organisé, la reprise précoce de compressions thoraciques est fortement associée à la refibrillation (figure 9). Plus la reprise des compressions est tardive par rapport au choc, plus les refibrillations sont également retardées voire absentes. Ce constat s'est vérifié lors de la transition entre les recommandations de 2000 (116) (qui indiquaient une prise de pouls après chaque choc), et celles de 2005 (117) (qui demandaient de reprendre immédiatement les compressions thoraciques (50,118)), ou sur des cohortes parisiennes très récentes (48).

Cette refibrillation, possiblement induite, ne suffit pas à faire peser la balanc bénéfice/risque en défaveur de la reprise des compressions thoraciques immédiatement après le choc :

- quand bien même la défibrillation est, au final, suivie d'une RACS, le pouls est rarement palpable juste après le choc (asystolie ou pseudo dissociation électro-mécanique temporaire). Il semble que 25% de ces situations puissent atteindre jusqu'à deux minutes (47) ;
- le lien de causalité n'est pas certain (119) ;
- le no-flow induit (augmentation du temps sans massage, ou « hands-off time » en péri-choc) est un facteur pronostic défavorable majeur (60) ;
- la stratégie d' « *immediat Cardio Pulmonary Resuscitation* » (vs « *delayed CPR* ») semble être associée à une meilleure survie globale (120).

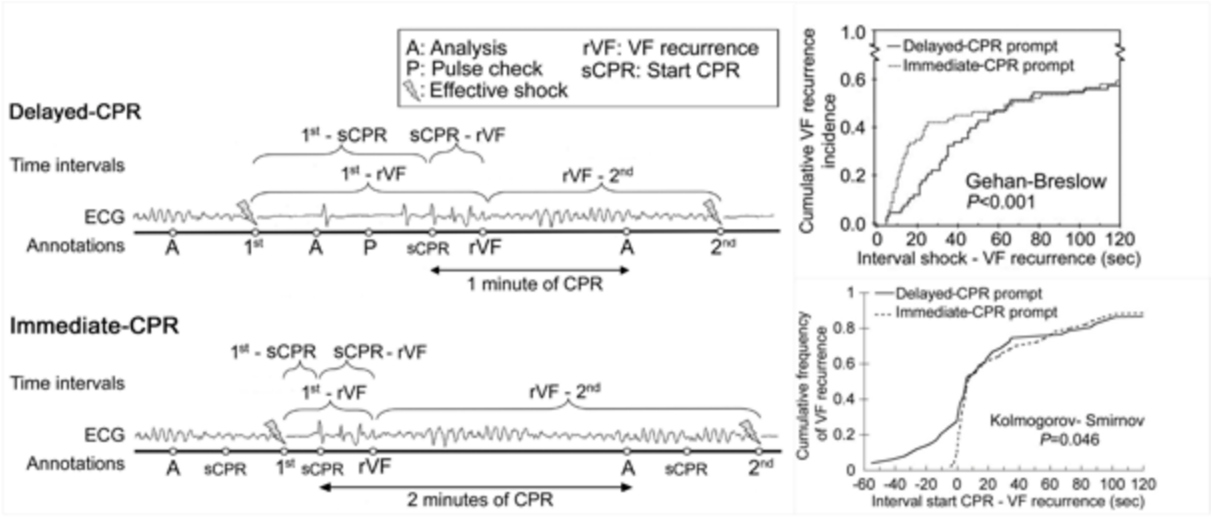

Figure 9: Transition entre les recommandations de 2000 et de 2005, taux de refibrillation selon la vitesse de reprise des compressions thoraciques après le choc (selon Berdowski et al, (118))

Plusieurs travaux rapportent comme possible la « *hands-on defibrillation* » c'est à dire la défibrillation sans interruption des compressions thoraciques. Cette technique, fait peser la question des risques d'électrisation induits pour les secouristes qui touchent le thorax au moment de la délivrance du choc. Ces risques paraissent, *in silico,* réduits par la protection offerte par les gants simples en latex, mais le risque de déchirure des gants reste réel. Elle permettrait l'avantage théorique d'une défibrillation à pause péri-choc nulle - cette pause étant, au-delà de son influence sur le *CCf*, une variable pronostique isolée -. Elle permettrait, de surcroît et en cas d'utilisation de compressions thoraciques mécanisées synchronisées avec un défibrillateur, d'appliquer les chocs en début de phase de décompression (121). Ce moment précis apparaît comme la période du cycle compression/décompression la plus favorable pour qu'un choc obtienne une RACS. C'est l'instant où l'impédance thoracique liée au faible volume d'air est la plus faible, mais également possiblement à des changements géométriques cardiaques (122). Le *« hands-on defibrillation »* n'a pas, cependant, d'efficacité clinique démontrée et n'est pas recommandée (123–125).

1.3.4. Ventilation

Recommandations après recommandations, la ventilation occupe une place de moins en moins importante dans la réanimation des AC (au contraire des compressions thoraciques), à l'exception des patients dont l'hypoxie est l'étiologie suspectée. Les recommandations de 2020

vont même jusqu'à proposer comme une pratique possible, des compressions thoraciques continues sans ventilation pour les arrêts cardiaques chocables devant témoin, même en présence de secours médicaux (60).

Il est recommandé aux témoins non entrainés de pratiquer des compressions sans ventilation. Les opérateurs de centre de secours ne guident que des compressions thoraciques lors du dépistage des AC (117). La ventilation est réservée aux témoins entrainés, mais surtout aux secours. Tant que le patient n'est pas intubé, la ventilation sera donc délivrée au ballon, enrichi en oxygène à un débit de 15L/min. Deux ventilations seront délivrées, chacune en 1 seconde puis 30 compressions seront administrées. Réputée difficile, la ventilation au ballon peut être simplifiée par l'utilisation d'un dispositif supra-glottique dès les premiers secours professionnels (recommandation de grade 2B). Les ventilations se doivent de limiter leur volume, une insufflation excessive pouvant être à l'origine de diminution du retour veineux et d'augmentation du risque de régurgitation (126): elles doivent être stoppées dès que le thorax se soulève. Le temps dédié à la ventilation se doit d'être réduit, pour conserver un CCf >60-80% (107,108), cependant la recommandation de 2 ventilations en 3 secondes paraît non réalisable : 5 secondes apparaissent le temps minimal pour les délivrer (127).

Une fois le patient intubé, un volume courant de 500-600mL chez l'adulte, à une fréquence de 10 cycles/minute est recommandé. Cette ventilation peut alors se désynchroniser des compressions thoraciques, qui deviennent ininterrompues (analyse de défibrillateur exclue).

1.3.1. Réanimation médicale

La réanimation médicale associe un certain nombre de gestes. L'intubation oro-trachéale, n'a pas apporté de preuve de gain sur la survie dans des études récentes de bonne qualité. Sur le plan théorique, sont en défaveur : l'arrêt des compressions thoraciques pour la réalisation du geste chez les opérateurs non experts, le passage à un régime de ventilation positif plus important que la ventilation au masque qui diminue du retour veineux et donc la précharge. Sont en faveur l'optimisation de l'hématose (possible cause curable), la sécurisation des voies aériennes et l'optimisation éventuelle d'une valve d'impédance thoracique. L'intubation reste présente dans les recommandations, pour les équipes expertes et avec un entrainement adéquat (113,128,129) ;

L'utilisation d'adrénaline, puissant vasoconstricteur périphérique augmente la pression de perfusion cérébrale et coronaire. Elle a également un effet inotrope et bathmotrope positif. Cependant, au niveau micro-circulatoire, ses effets ne semblent pas univoques et pourraient

contre balancer les effets macro-circulatoires positifs. Elle est recommandée à la posologie de 1mg/3-5 minutes chez le patient avec un rythme non-chocable ou bien après le 3ème et 5ème choc chez le patient chocable, selon les recommandations depuis 2010. Deux études récentes randomisées, les méta-analyses qui les ont poolées et les analyses en sous-groupe permettent une approche un peu plus fine, bien qu'encore imparfaitement robuste (130–132) :

- son utilisation augmente les taux de RACS et l'admission vivant à l'hôpital, mais pas le taux de survie avec bon pronostic à 3 mois ;
- sa précocité d'administration paraît associée à un meilleur taux de RACS ;
- le bénéfice de l'adrénaline paraît être supérieur chez les patients présentant un rythme non chocable à l'arrivée des secours ;
- les hautes doses d'adrénaline (0,1-0,2mg/kg) présentent dans de nombreuses études, des résultats contrastés : parfois améliorant le ROSC ou l'admission vivant à l'hôpital, en tout cas, jamais associées à un gain de survie avec bon pronostic à 3 mois (128).

Il est possible d'utiliser la vasopressine : cette amine a été comparée à de l'adrénaline ou à une association adrénaline/vasopressine. Elle n'a jamais apporté la preuve de sa supériorité. Elle reste d'usage possible, sans recommandation d'utilisation supérieure à l'adrénaline. Elle n'est pas, en France, d'usage courant (133).

Il est possible d'utiliser de l'amiodarone. Depuis 2005, il est recommandé l'injection de 300mg d'amiodarone en intraveineux direct après le 3ème choc (et 150mg après le 5ème choc). Un essai randomisé récent de qualité a apporté la preuve de l'amélioration du taux de RACS et d'admission hospitalière pour les patients en VF récidivante ou réfractaire recevant de l'amiodarone, sans effet sur la survie avec bon pronostic neurologique à la sortie de l'hôpital (134). Il a été évoqué son administration trop souvent tardive, en phase métabolique, là où une utilisation lors des deux premières phases de l'AC semblerait plus efficiente pour lutter contre la récidive de VF (voir 1.1.8).

Une recherche des causes curables doit être réalisée. Elle peut permettre une amélioration franche du pronostic. Cependant, celle qui concerne la défibrillation (la thrombose coronaire) n'a pas de traitement per AC spécifique. La thrombolyse, en particulier, n'est pas recommandée dans cette indication et reste limitée et peu efficace pour les embolies pulmonaires prouvées avant l'AC ou fortement suspectées (135).

Le reste des actions médicales possible n'est pas détaillé ici, en l'absence de lien avec la défibrillation.

1.4. DEFIBRILLATION

1.4.1. Modalité de défibrillation

1.4.1.1. Interface et position

La défibrillation initiale n'est pas significativement différemment efficace, que les électrodes se situent en antéro/postérieur, en antéro/latéral et en antéro-supéro-latéral-droit/infra-scapulaire gauche : des différences existent pour le traitement des fibrillations atriales, mais n'ont jamais été retrouvées pour le traitement des *coarse VF* pour les patients en AC (136,137). Les électrodes antéro/latérales peuvent, en revanche, être mises en place sans arrêt de la délivrance des compressions thoraciques ni retournement du patient. L'axe de défibrillation est pourtant une piste sérieuse d'amélioration d'efficacité, à la fois en corrigeant le placement des électrodes (l'électrode latérale est souvent trop antérieure et caudale), mais également, en réalisant une double défibrillation séquentielle (défibrillation avec un premier DSA avec électrodes antéro/latérales immédiatement enchainées avec une défibrillation antéro/postérieure grâce à un deuxième DSA). Une étude très récente rapporte un gain de survie avec cette méthode, voire en changeant d'axe pour passer d'antéro-latéral à antéro-postérieur après 3 défibrillations non efficaces (138).

Pour un défibrillateur manuel, l'impédance thoracique d'un adulte est classiquement de 70-80 Ω. Une impédance plus élevée (thorax large, emphysème pulmonaire par exemple) diminue l'intensité d'énergie délivrée et le succès de défibrillation. Pour limiter l'impédance liée au passage du courant entre l'électrode et la peau, les électrodes doivent posséder une certaine taille, c'est à dire une surface d'au moins $8cm^2$, mais préférentiellement de $12cm^2$ (139).

Il s'agit désormais, quasi exclusivement en extrahospitalier d'électrodes adhésives porteuses de gel ; l'ILCOR a même retiré les références liées aux palettes tenues à la main avec interposition manuelle de gel devant leur rareté d'utilisation, bien que leur usage n'ait pas été prouvé significativement moins efficace (60,114). Enfin, les défibrillateurs semi automatiques modernes mesurent l'impédance du thorax de manière continue et adaptent l'intensité du choc à l'impédance mesurée (140). Cette mesure continue de l'impédance est, en outre particulièrement utile pour l'analyse des tracés de défibrillateurs, puisqu'elle permet au relecteur d'identifier les périodes de massage, de ventilation ou de gasp (voir 1.1.3 et 3.4.)

1.4.1.2. Energie et forme d'ondes

La quasi-totalité des défibrillateurs modernes utilise désormais des ondes de défibrillation diphasiques. Elles n'ont jamais apporté la preuve de leur supériorité sur les monophasiques sur la survie des patients, même si elles sont réputées obtenir plus souvent une résolution des VF. Cependant, à efficacité égale, elles exposent le myocarde à une intensité électrique moindre, ce qui est, théoriquement plus sécuritaire pour les intervenants comme pour les patients (60,141,142). De même, les constructeurs ont développé plusieurs formes d'ondes biphasiques de défibrillation, dont aucune ne paraît supérieure aux autres (143).

A efficacité non significativement différente, et avec des formes d'ondes variables, il est compliqué de parler de niveau d'énergie pour la défibrillation dans les AC, tout du moins comme élément de comparaison entre modèles de défibrillateurs. Pour l'intensité de défibrillation, les dernières recommandations proposent de suivre les recommandations de chaque constructeur. En cas de VF récidivante ou réfractaire il est recommandé d'utiliser des chocs d'intensité identique ou supérieure au premier choc : l'étude BIPHASIC a montré une meilleur efficacité d'une séquence d'escalade dans l'intensité des chocs, sans apporter, cependant, la preuve d'un gain sur la survie (120,144).

1.4.1.3. Types de défibrillateurs

Les défibrillateurs manuels font reposer sur un opérateur - médecin dans notre système de soins - le choix du moment d'analyse, la conduite de l'analyse, sa durée, la décision choc/non choc, l'intensité de défibrillation, le moment de la charge des condensateurs et le moment de délivrance du choc.

Les défibrillateurs semi-automatiques (DSA) utilisent un algorithme informatique pour proposer le moment de l'analyse, analyser le tracé électrocardiographique, proposer (ou non) un choc puis le délivrer en cas d'appui sur un bouton mécanique. L'intensité du choc est préréglée dans l'algorithme et adaptée à l'impédance mesurée. Les DSA communiquent avec les secouristes par le biais d'annonces vocales préenregistrées qui demandent l'arrêt des compressions thoraciques, l'appui sur le bouton choc, la connexion des électrodes etc. Les défibrillateurs automatiques se distinguent des DSA par la délivrance de choc sans appui sur un bouton.

A Paris, nous l'avons étudié, tous les défibrillateurs présents dans l'espace public, comme ceux des premiers secours (pompiers, ambulanciers, associations de secourisme) sont des DSA

(35). Les défibrillateurs médicaux offrent tous la possibilité de défibrillation manuelle et pratiquement toujours un mode « DSA ».

Les performances des DSA sont données par chaque constructeur et publiées (145–147). Pour un DSA donné, la performance est quasiment inchangée dans le temps et pour différents patients. La performance du *software* (de l'algorithme) est même constante, ce sont les informations qui lui parviennent qui vont faire varier parfois ses décisions : problèmes d'électrodes (sèches et provoquant une impédance trop importante, non adhérentes avec perte de signal), interférences électriques causées par présence d'un pacemaker, présence de gasps importants du patient mimant des mouvements (148). Certaines étude retrouvent jusqu'à 20% de DSA publics non fonctionnels, dont la moitié pour des électrodes périmées (149). A l'inverse, les défibrillateurs manuels ont une performance qui dépend du praticien, et pour le même praticien, avec une probable variabilité dans le temps, et entre les patients. Notre travail, en 3.5. étudie les préférences des médecins pour le choix des défibrillateurs manuels/DSA et leurs performances.

1.4.2. Cinétique de la défibrillation au sein d'un cycle

La réanimation d'un patient en AC, une fois connecté à un DSA, peut être découpée en cycles, habituellement de deux minutes. Usuellement, il existe deux phases dans un cycle : une phase d'analyse et une phase de réanimation cardio-pulmonaire. Le premier cycle commence par la première analyse. Il n'est pas recommandé de réaliser systématiquement des compressions thoraciques avant la première analyse. Pragmatiquement, il est conseillé d'en prodiguer le temps d'acheminer un DSA, de l'allumer, de positionner les électrodes et de les connecter. Il demandera l'arrêt des compressions en lançant immédiatement sa première analyse (150).

1.4.2.1. Phase d'analyse

La phase d'analyse requiert classiquement l'arrêt des compressions thoraciques. Les algorithmes de défibrillation nécessitent, en effet, un tracé électrocardiographique exempt d'interférences causées par ces compressions thoraciques ou d'autres mouvements du patient ou des secouristes. L'algorithme récupère cette information via l'analyse de l'impédance thoracique. Si l'on estime que cette phase d'analyse a pour unique objectif de choquer les rythmes chocables, on peut donc dire que cette phase est un pari, puisqu'elle accepte une prise

de risque (arrêt des compressions thoraciques occasionnant un effondrement des pressions de perfusion cérébrales, myocardiques, splanchniques) pour espérer un gain (détection d'un rythme chocable, puis défibrillation, dans l'espoir de restaurer un rythme organisé). Cette pause peut être également utilisée pour que les secouristes se relayent aux compressions thoraciques, pour que chacun ne masse pas plus de 2 minutes, durée réputée au-delà de laquelle les compressions perdraient en efficacité du fait de la fatigue des masseurs. Cette durée est recommandée depuis 2005 (151), même si certains pays utilisent 3 minutes (152) et que notre travail en 3.4. propose des durées de phase de RCP adaptée au rythme sous jacent.

La phase d'analyse d'un DSA, vue d'un utilisateur, s'organise comme suit : annonce vocale demandant l'interruption des compressions thoraciques, puis analyse du tracé électrocardiographique, demande éventuelle d'appui sur le bouton choc, délivrance éventuelle du choc (si choc recommandé, et si appui du bouton dans les 20 secondes, et si pas de détection de mouvement), demande de reprise du massage. Le temps entre la dernière compression thoracique et l'éventuel choc est appelé pause pré-choc ; celui entre le choc et la reprise des compressions thoraciques est appelé pause post choc. Ces deux temps, additionnés, constituent la pause péri-choc.

Pour optimiser la survie, il convient qu'elle soit la plus réduite possible, surtout la pause pré-choc. Deux avancées technologiques récentes permettent de la raccourcir :

- les DSA récents rechargent systématiquement les accumulateurs plusieurs secondes avant l'annonce de l'analyse pour qu'une éventuelle décision de choc puisse être exécutée immédiatement, sans temps de charge. Cette charge avant analyse n'est pas toujours possible avec les défibrillateurs manuels et requiert une assez grande expertise des médecins qui la pratiquent (153–155).
- Certains DSA, dont ceux du travail présenté en 3.4. sont équipés d'une analyse dite « par antériorité ». En effet, le DSA réalise une annonce vocale pour demander l'arrêt des compressions thoraciques, mais cet arrêt est, dans les faits, parfois anticipé par les secouristes. Ce temps « fin de compression thoracique anticipé– annonce vocale (et donc début d'analyse) » est perdu pour les algorithmes classiques. L'analyse par antériorité permet d'initier l'analyse dès la fin des compressions thoraciques, que celles-ci se situent avant ou après l'annonce vocale, et de gagner 6-10 secondes de pause pré-choc (156).

1.4.2.2. Phase de réanimation cardiopulmonaire, analyse sous massage

La phase de réanimation cardio-pulmonaire est consacrée aux compressions thoraciques et à la ventilation. Certains DSA proposent un métronome pour guider le rythme de ces compressions, avec une efficacité clinique présumée (157,158).

Cependant, pour optimiser le pari évoqué en 1.4.2.1, plusieurs technologies ont été développées depuis quelques années pour permettre l'analyse du tracé électrocardiographique sans interruption des compressions thoraciques (159–161).

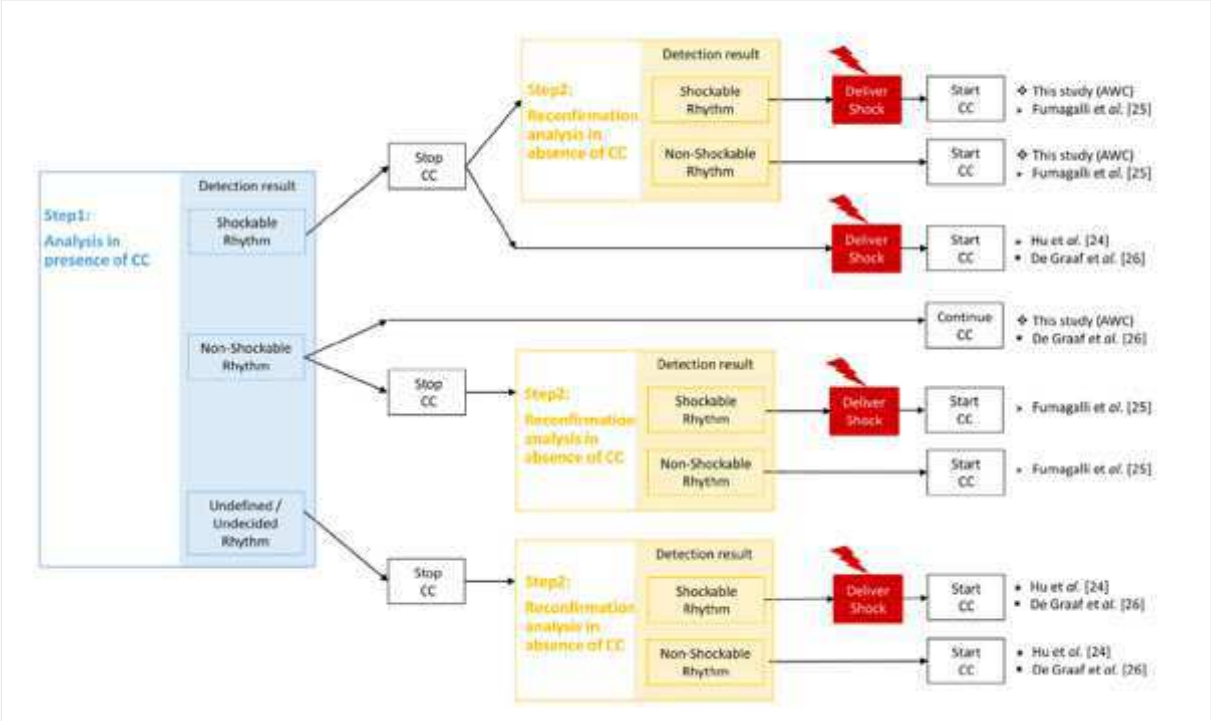

Figure 10: Différents types d'algorithmes utilisant la détection pendant les compressions thoraciques, selon Didon et al (162).

Une première étude clinique a été publiée qui montrait une maturité du système avec des analyses sous massage autant sensibles et spécifiques que les analyses hors massage et avec un *CCf* significativement supérieur (163). Nous présentons, en 3.4. les résultats de notre étude qui utilise une autre technologie. Il est à noter que différents constructeurs ont désormais des algorithmes utilisant l'analyse sous massage, dans plusieurs configurations (voir figure 10). Toutes ne sont pas encore d'usage commercial courant :

- analyse sous massage demandant une analyse sans massage « de reconfirmation » en cas de rythme chocable détecté. Cette analyse de confirmation est systématique, à l'inverse jamais proposée, ou bien proposée en cas d'incertitude (Philipps ©) (164).

- analyse sous massage respectant toujours les 2 minutes de constitution d'un cycle. C'est à dire, analyse sous massage conduite uniquement à la fin des 2 minutes de la phase de massage d'un cycle (Zoll ©, Stryker ©) (165). Ceci permet de limiter le temps d'analyse toutes les 2 minutes. A l'inverse, analyse sous massage conduite dès la fin de la première minute post choc permettant de proposer une analyse de reconfirmation dès la détection d'un rythme chocable sous-jacent (Schiller ©) (162). Ceci vise à traiter plus rapidement les refibrillations.

1.4.3. Améliorer la défibrillation

1.4.3.1. Intérêt de réduire les délais

La défibrillation est, pour la grande majorité des AC d'origine médicale, le moment où l'activité cardiaque peut redevenir efficace durablement. En effet, le taux de survie des patients n'ayant jamais reçu un choc électrique est de 2,5% lorsque celui de ceux choqués à la première analyse peut atteindre 25% à 50% (78,166). Il existe une interaction très forte entre le *no-flow*, le *low-flow* et la défibrillation. En effet, classiquement, plus la défibrillation est précoce après l'effondrement, plus les chances que le patient présente un rythme chocable sont élevées, plus ce rythme chocable a une amplitude électrique élevée, plus il présente de chance d'être résolu par un choc pour obtenir un RACS et meilleur est le pronostic neurologique (66,80). Cela est prouvé depuis les années 1980-2000 dans des circonstances variées : casino avec personnels entraînés, aéroports avec personnes non entraînées, mais également en situation de ville classique avec défibrillation par des secouristes, des policiers ou de simples témoins (166–172).

Raccourcir l'accès à la défibrillation est donc tout particulièrement intéressant en termes d'impact potentiel sur la survie (74,158). «*Early defibrillation is the single greatest determinant of survival for adult victims of cardiac arrest* » (174). Cela est vrai pour pratiquement tous les CA. Les recommandations de 2000 l'expliquaient ainsi : les secours doivent considérer que tous les AC sont causés par une VF. L'application d'un choc sur un rythme chocable est à l'origine de pratiquement tous les survivants d'AC (85-95%) (7). Enfin, la qualité et l'espérance de vie d'un patient en AC choqué rapidement sont les mêmes que celles des personnes de sa classe d'âge aux comorbidités identiques n'ayant pas réalisé d'AC (175).

1.4.3.2. La défibrillation n'est plus l'apanage des secours sur le terrain : la fin d'un paradigme

La défibrillation est représentée, dans la chaîne de survie de l'arrêt cardiaque princeps comme le 3ème maillon sur 4. Historiquement, elle n'était possible que par les secours médicaux, puis, lors de l'arrivée des DSA, elle s'est diffusée parmi les secouristes, et enfin, pour le grand public. Depuis une vingtaine d'années, la structure de la chaîne de survie est moins stricte et la défibrillation peut désormais intervenir pendant les premiers maillons de la chaîne de survie (176): utilisation d'un défibrillateur public, citoyens sauveteurs (177), drone défibrillateur (178).

L'incidence de cette défibrillation avant l'arrivée des secours augmente. Entre 2006 et 2013, les pays nordiques sont passés de 10% à 30% des survivants ayant été défibrillés par un DSA public (61).

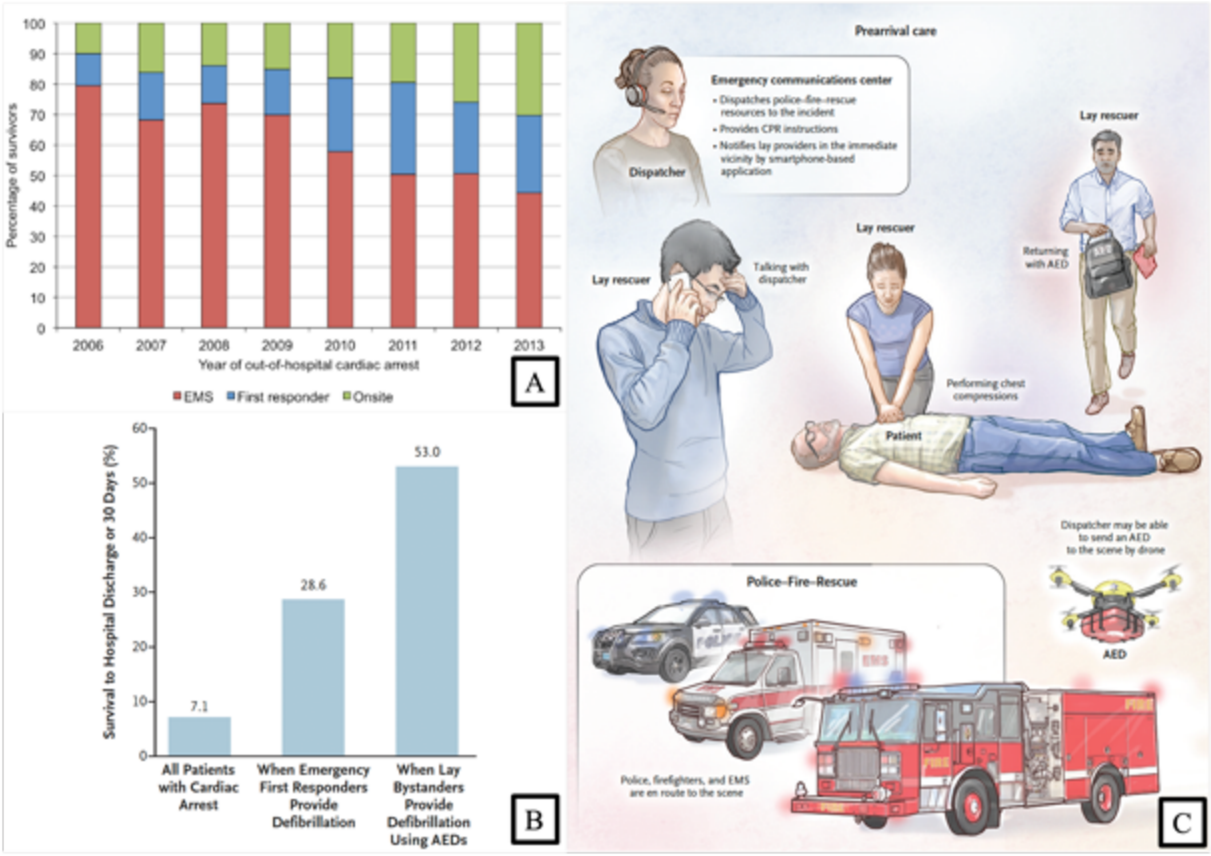

Figure 11. Modification de la personne réalisant la défibrillation (EMS : Emergency Medical Services) (panel A. selon Ziljstra et al. (61)). Efficacité de la défibrillation en amont des secours sur la survie (panel B. selon Brady et al. (176)). Défibrillation via les témoins, les applications de citoyens sauveteurs et les drones (panel C. selon Brady et al.(176)).

1.4.3.3. Améliorer la défibrillation via le grand public *: la structuration d'un process*

L'amélioration de la défibrillation par le grand public s'appuie sur les *Public Access Defibrillation programs (PAD)*. Ils visent un but simple : améliorer l'accès des AC à une défibrillation la plus précoce possible. Cependant, qu'un patient bénéficie d'un AC avant l'arrivée des secours relève, en réalité, d'un process assez ambitieux (figure 12). Les PAD ont des implications assez complexes, scientifiques, légales, technologiques, mais également sociologiques (15,179,180). Le développement de ces *PAD* est fortement recommandé (181), et leur efficacité sur la survie à la sortie de l'hôpital a déjà été prouvée (182,183). Ces PAD peuvent exister à l'échelles de pays, mais également de départements ou de communautés.

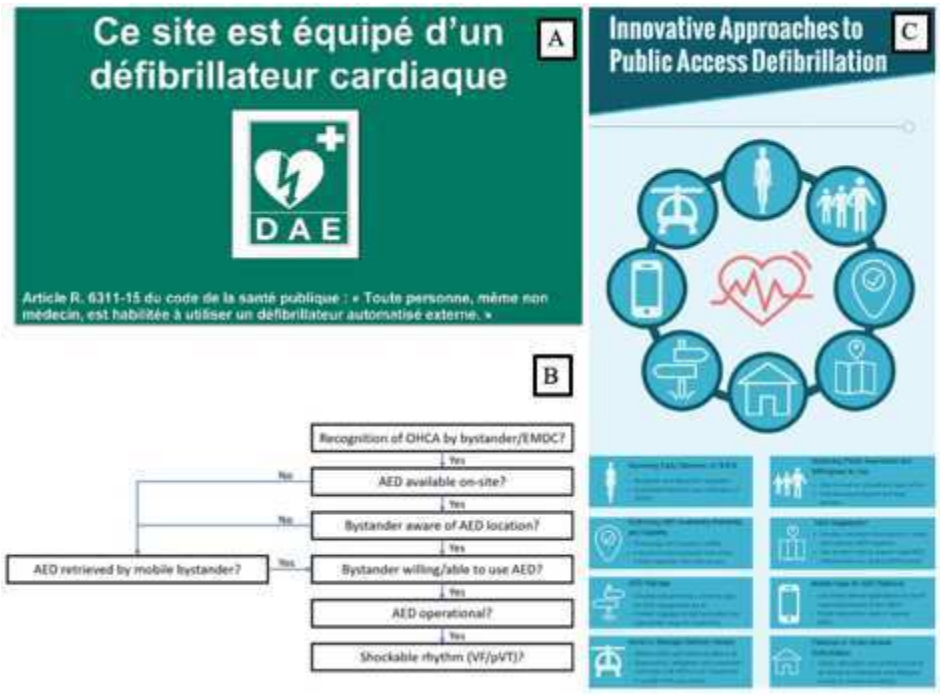

Figure 12: Signalisation règlementaire des défibrillateurs en France (Panel A, (184)) ; Cascade des difficultés pour défibriller un AC avant l'arrivée des secours (Panel B, selon Ring et al., (185) ; Construction d'un Public Access Defibrillation (panel C selon Brooks et al. ((15))

Un *PAD* s'appuie donc sur de multiples actions. Tout d'abord il convient d'améliorer la détection des AC par les dispatchers et la formation globale du grand public (104,186). Cette dernière est un facteur important pour l'utilisation de DSA publics. Une étude retrouve une

formation dans les 5 années précédant comme multipliant par 5 les chances d'utilisation d'un DSA public (187). Depuis 2007, en France, un décret autorise toute personne (même non médecin) à se servir d'un DSA (188) ;

Ensuite, il faut améliorer la disponibilité des DSA existants (189,190). La densité de DSA en est un premier facteur. Dans les zones urbaines les mieux dotées seuls 3 à 25% des AC se produisent à moins de 100 mètres d'un DSA. Il semble très difficile de faire utiliser avant l'arrivée des secours un DSA positionné à plus de 200 mètres de l'AC. Au-delà du seul nombre, leur répartition est importante. Elle a bénéficié de multiples approches, avec modélisations mathématiques sur les endroits où se produisent le plus d'AC, en lien avec des études sociologiques et socio-économiques (191,191). Lorsqu'ils sont proches, les DSA ne sont pas toujours accessibles, spécialement la nuit (la disponibilité des DSA diminue de 60% la nuit, pendant laquelle se produit 60% des AC), ou dans les étages des immeubles (192,193). Une étude rapporte un effondrement de la survie, inférieure à 1% à partir du 16ème étage et à 0% en cas d'AC au-delà du 25ème étage (194). La crainte de vol de DSA est très nettement surestimée, puisque rarissime dans la littérature (0,3% par an) (195). En revanche, mettre à disposition les DSA dans des endroits très accessibles (extérieurs) implique de les protéger du froid et de l'humidité, ce qui en augmente le coût. Enfin, la disponibilité des DSA requiert une amélioration de l'entretien des DSA, puisque jusqu'à 15% des DSA installés semblent non fonctionnels dans certaines séries (15,196). Depuis 2018, en France, les établissements recevant du public sont dans l'obligation de disposer d'un DSA et d'en assurer la maintenance (197). Dans certains pays d'Europe (Pays-Bas par exemple), l'association qui anime la communauté de citoyens sauveteurs gère également une certaine politique de répartition des défibrillateurs. Ils peuvent ainsi identifier les zones dépourvues et solliciter, spécifiquement pour un quartier, un financement collaboratif pour qu'aucune zone résidentielle ne se trouve à plus de 3 minutes de marche d'un défibrillateur.

L'amélioration de la signalisation des DSA et l'amélioration des cartographies des défibrillateurs est un des axes de *PAD*. En 2018, en France, l'obligation légale d'enregistrer son DSA s'impose, en même temps que la création d'une base nationale informatisée des défibrillateurs (198) (https://www.data.gouv.fr/fr/datasets/geodae-base-nationale-des-defibrillateurs/). En 2019, un arrêté précise les modalités de signalisation légale des DSA (184) (figure 12). Il est recommandé que les centre d'appel d'urgence utilisent cette cartographie pour guider les témoins vers un DSA, tout comme il est recommandé de développer des applications pour smartphone pour que les témoins s'en servent pour localiser les DSA les plus proches (15) ;

Pour réduire le délai à la défibrillation, il est possible de créer et d'utiliser une communauté de citoyens sauveteurs (voir notre travail en 3.2.). Il s'agit de référencer des citoyens volontaires, formés ou non aux gestes des premiers secours et qui, au moyen d'une application smartphone dédiée, reçoivent une alerte en cas d'AC à proximité. Ils sont alors dépêchés pour réaliser des compressions thoraciques et/un utiliser défibrillateur avant l'arrivée des secours. Une telle communauté doit être recrutée et animée pour disposer d'un vivier important afin que chaque alerte parvienne à plusieurs citoyens volontaires. Le meilleur ratio de citoyens envoyés pour masser ou pour chercher un défibrillateur est inconnu. Il dépend probablement de la réalisation de gestes par le témoin, du délai de présentation supposé des secours et du maillage géographique en DSA publics (15). Il fait l'objet d'approches empiriques, sans étude de bonne qualité permettant une application précise en pratique. Depuis 2020, en France, ces citoyens sauveteurs disposent d'un statut juridique protecteur. La même loi renforce les cours de formation aux premiers secours à différents niveaux scolaires ainsi que les sanctions en cas de dégradation des DSA publics (199). Les systèmes de citoyens sauveteur sont efficaces pour réduire la mortalité des AC (200,201). Leur utilisation est recommandée par l'ILCOR depuis 2022, et la société française de médecine d'urgence est en train de rédiger des recommandations d'utilisation (15).

Enfin, la défibrillation via des vecteurs innovants est utile. Celle-ci peut être effectuée par des policiers équipés ; elle a prouvé une réduction du délai effondrement-défibrillation et une augmentation du nombre de rythmes chocables initiaux (202). Les défibrillateurs à demeure à domicile ne semblent pas, eux, apporter de gain de survie (203,204). L'envoi de drone-défibrillateur par les secours permet également de défibriller précocement et avant l'arrivée effective des pompiers. Le premier patient défibrillé par cette méthode l'a été, en 2022, en Suède (178), après de très nombreux travaux préparatoires (205).

1.4.3.4. Améliorer la défibrillation des secours

Tout comme le positionnement des DSA publics est important pour augmenter leur utilisation, le pré-positionnement des équipes de secouristes au plus près des AC probables est intéressant. Par exemple, des équipes japonaises ont prépositionné des secouristes à pied ou à vélo environ tous les kilomètres pendant 251 épreuves de course à pied, avec 28 survivants pour 30 coureurs ayant présenté un AC, soit taux de survie de 93%, tout à fait exceptionnel (206).

Des avancées technologiques comme la détection de récidive de fibrillation per massage par le DSA ou la prédictibilité de la réussite d'un choc pour résoudre la *Coarse VF* sont déjà utilisés en pratique courante ou arrivent dans un futur proche.

Pour les secours utilisant des défibrillateurs manuels, il semble qu'une marge de progression dans l'exactitude de la décision choc/non choc existe. Cependant l'utilisation d'un défibrillateur manuel entraîne une pause périchoc plus courte que celle des DSA (207). Pour être tout à fait précis, le plus souvent, un défibrillateur manuel est associé à une pause courte… cependant, le défibrillateur manuel étant très rarement chargé avant cette analyse manuelle, il existe, ou bien une reprise des compressions thoraciques (et, *in fine,* deux interruptions de délivrance des compressions thoraciques au lieu d'une) ou bien une pause comprenant l'analyse et la charge de défibrillateur. Le travail de Kramer et al (210), qui date d'une quinzaine d'année, ne prend pas en compte les améliorations de vitesse de décision des DSA les plus récents (156). Notre travail, en 3.5. étudie ce point.

2. OBJECTIFS ET METHODE DE CETTE THESE

La prise en charge des AC est extrêmement polymorphe. Pour les effecteurs, elle fait intervenir des témoins non formés et d'autres formés, des secouristes en centre d'appel téléphonique et d'autres sur le terrain, des équipes médicales en centre d'appel, préhospitalières puis hospitalières ; pour les décideurs, elle s'appuie sur un travail pédagogique, technologique, législatif, médical, ergonomique, linguistique, social, éthique etc.

La multiplicité des solutions pour réduire le délai d'accès à la défibrillation préhospitalière et son intrication très forte avec la survie des patients en AC a suscité notre intérêt (179). Nous avons donc choisi une approche originale. Nos études se sont portées :

- à la fois sur des maillons différents de la chaîne de survie : centre de régulation, premiers secours et secours médicalisés ;
- à chaque fois, via des approches méthodologiques différentes ;
- à des stades d'avancée différents. Deux travaux ont constitué, entre autres, à mesurer la performance de systèmes déjà existants, ces mesures ont été intrinsèquement porteuses d'améliorations (études 3.1 et 3.5) ; d'autres ont été le co-développement de systèmes puis l'analyse de leurs résultats (études 3.2 et 3.4) ; enfin, un dernier a été à l'initiative d'un nouveau système (étude 3.3).

Pour ces travaux, nous avons été moteur des avancées des projets. Cependant, certains existaient avant notre implication, et surtout aucun n'aurait pu se concrétiser sans une équipe pédagogique, scientifique et opérationnelle extrêmement motivée et ayant une connaissance experte du fonctionnement de la prise en charge des AC, de l'appel à la médicalisation. Au sein de ce groupe, nous avons progressé de manière très importante en clinique, en recherche scientifique dans tous ses aspects. Ce groupe, composé d'infirmiers, de médecins juniors, seniors, de cliniciens, de statisticiens et d'attachés de recherche clinique ou règlementaire est nommé « Cardiac Arrest Task Force des Pompiers de Paris ». Il est co-auteur de tous ces travaux, qui n'auraient pas pu voir le jour sans chacun de ses membres. Il s'articule avec le Centre d'Expertise de la Mort Subite, structure de formation, de prise en charge clinique et recherche parisien.

Notre manuscrit présente ainsi les résultats de travaux de recherche publiée via :

- 1. Une étude cross-sectionnelle sur la performance d'un centre de réception des appels d'urgence pour la détection des arrêts cardiaques et l'utilisation des défibrillateurs publics (186) ; voir 3.1. ; 2019

- 2. Une étude rétrospective monocentrique sur l'efficacité d'une application de citoyens sauveteurs pour permettre la défibrillation (208) ; voir 3.2. ; 2020
- 3. Une simulation numérique complexe pour mesurer l'intérêt de drones-défibrillateurs dans un centre urbain très dense (209) ; voir 3.3. ; 2021
- 4. Une étude clinique de type avant/après, monocentrique, modifiant l'algorithme d'analyse et de défibrillation des défibrillateurs des pompiers de Paris pour essayer de raccourcir le délai de choc électrique des patients présentant une refibrillation ; voir 3.4. ; soumis en 2024
- 5. Une étude prospective multicentrique en simulation sur les pratiques et la performance de défibrillation des médecins urgentistes préhospitaliers (210) ; voir 3.5. 2022

3. RESULTATS

3.1. Améliorer la défibrillation via la mesure de la performance des opérateurs du 18-112

Nous avons réalisé une étude cross-sectionnelle rétrospective par écoute de bandes téléphoniques sur 4 périodes distinctes. *Improving emergency call detection of Out-of-Hospital Cardiac Arrests in the Greater Paris area: Efficiency of a global system with a new method of detection* a été publié dans le journal Resuscitation (186).

3.1.1. Méthodologie

Nous avons conduit ce travail avec l'équipe de recherche scientifique des pompiers de Paris qui avait validé la méthode du « top ventre » pour dépister les AC (104). La méthodologie a été globalement identique à ce travail initial de 2012, afin de permettre la comparaison avec 3 périodes supplémentaires (2015, 2017 et 2018). Nous avons ajouté d'autres variables d'étude : quantifier le temps perdu lors de différentes parties de l'appel (envoi de l'appel / dépistage de l'AC / guidage des compressions thoraciques) en catégorisant ce temps perdu selon son origine présumée : technologique, à imputer au requérant téléphonique ou à l'opérateur. Nous avons pu confronter nos résultats à ceux recommandés par la AHA depuis 2018 sur leur site internet, et publiés en 2020 (92).

3.1.2. Impact des résultats, reconnaissance des travaux

Ce travail a permis de mesurer tout à la fois une très grande amélioration des performances de détection des AC entre 2012 et 2018, mais également une amélioration du nombre de patients recevant un guidage des compressions thoraciques. Intrinsèquement, il a permis d'asseoir la validation de la technique du « top ventre » et de renforcer l'adhésion des opérateurs pompiers du 18/112 à cette technique. Il y a eu, au fur et à mesure des périodes, l'émergence des premières recherches et utilisations guidées de défibrillateurs, mais assez peu de défibrillateurs posés avant l'arrivée des secours.

L'expertise développée par l'écoute de ces environs 200 bandes téléphoniques nous a permis, avec les responsables scientifiques et pédagogiques des opérateurs pompiers, d'affiner le protocole de guidage des gestes par les témoins. En particulier, la recherche d'un défibrillateur public est passé de la 10ème place dans les instructions délivrées aux requérants à la 2ème place. Un protocole de guidage de pose des différents modèles de DSA publics présents

sur le secteur BSPP a été ébauché avec des opérateurs (20 modèles différents recensés (35)). Malheureusement, ce projet-là n'a pas abouti pour l'instant.

Ce travail pourrait paraître éloigné de l'objectif de cette thèse sur la réduction du temps d'accès à la défibrillation. En réalité, la détection des AC est un préalable indispensable à la défibrillation et le premier pilier des PAD pour la défibrillation préhospitalière (voir 1.4.4.3.). De plus, l'organisation interne des appels de la plateforme des pompiers de Paris ne définit pas la recherche du DSA comme une tâche de l'opérateur ayant le requérant en ligne. Son chef de table peut chercher des DSA sur une cartographie, avec ou sans l'aide de citoyens sauveteurs. Cette recherche n'est pas accessible à notre méthodologie basée sur l'écoute des bandes téléphoniques et peut être à l'origine d'un biais minimisant la mesure de la recherche de DSA en centre d'appel.

Ce travail a bénéficié d'un éditorial lors de sa parution (211), et a été cité par 9 articles depuis sa publication, dont les recommandations de l'ERC de 2020 (212–220).

3.1.3. Connaissance de défibrillateurs publics : travail publié hors thèse (35)

Dans la même période que ce travail en centre appel, et faisant le lien avec les travaux présentés en 3.2.3., nous avons récupéré tous les tracés des défibrillateurs publics utilisés pendant 28 mois consécutifs sur les 4 départements de Paris et de la petite couronne (35). Pour les 182 tracés que nous avons récupéré de 20 modèles différents, provenant de 12 constructeurs différents, avec 16 logiciels dédiés, nous avons mesuré à la fois la performance (sensibilité / spécificité) de l'algorithme, mais également la qualité du tracé présenté. Une très grande majorité (98%) des tracés était lisible, cependant il manquait dans 1/3 des cas l'échelle du voltage et dans plus de la moitié des cas la courbe d'impédance. Au final, pour la plupart des tracés, l'exploitation médicale (certifier la présence d'un rythme chocable, attribuer le tracé au bon patient etc.) était difficile ; l'exploitation scientifique (horodatage des évènements, compréhension des phases d'algorithme du défibrillateur etc.) était difficile ; l'utilisation à des fins de matériovigilance était quasiment impossible (nom du constructeur, modèle du logiciel, date de la maintenance etc.).

Table 1 Relevance and frequency of 23 variables of public automated external defibrillator recordings

Variable		N	%
Readability of the ECG*		179	98%
Understandable algorithm notified events†		176	97%
Numbered pages		172	95%
Entire electrocardiographic trace		170	93%
Brand of the device		130	71%
Unique machine identification number		123	68%
Voltage scale		123	68%
Accuracy of the date		123	68%
Accuracy of the time		88	48%
Model of the device		87	48%
Event time stamping	Absolute schedule	99	54%
	Relative schedule	83	46%
Impedance trace		79	43%
Event summary		72	40%
Intensity of the shocks delivered		62	34%
Software version mentioned		57	31%
Vocal announcements of the defibrillator		40	22%
Type of shock delivery	Unknown	107	59%
	Manual	39	21%
	Fully automatic	36	20%
Adult/paediatric electrode model		20	11%
Patient name‡		15	8%
Date of last self-check and/or human maintenance		12	7%
Owner's identity		11	6%
Notion of a metronome		8	4%
Maintainer identity		0	0%

Figure 13 fréquence des variables établissant la qualité des tracés de défibrillation dans (35),

La performance des DSA public était globalement en dessous des standards usuels (Sensibilité de 87.7% [83.7-81.0] ; Spécificité de 99.5% [99.5-99.5]). Nous avons publié *Insufficient quality of public automated external defibrillator recordings in the greater Paris area, a descriptive study. Emerg Med;0:1-6* en 2020 (35). Nous n'avons pas souhaité l'inclure dans notre travail de these, puisque bien qu'il s'intéresse au sujet de la défibrillation, son apport dans la réduction du délai entre la fibrillation et la délivrance d'un choc n'était pas immédiat.

3.2. Raccourcir le délai de défibrillation extrahospitalier via une application de citoyens volontaires

Nous avons réalisé une étude rétrospective monocentrique sur l'efficacité d'une application (nommée StayingAlive) de citoyens sauveteurs (nommés Bons Samaritains) pour permettre la défibrillation. *Mobile Smartphone Technology Is Associated With Out-of-hospital Cardiac Arrest Survival Improvement: The First Year "Greater Paris Fire Brigade" Experience* a été publié dans Academic Emergency Journal (208).

Ce travail est un des deux qui nous a demandé le plus d'investissement. Nous avons été intégrés au projet peu après la réussite de son implémentation technique au centre d'appel des pompiers de Paris, et après de premiers tests sur des AC simulés avec des Bons Samaritains volontaires. Il n'y avait pas eu, encore, de déclenchement conduisant un Bon Samaritain à réaliser des compressions thoraciques avant l'arrivée des secours. Pour obtenir des résultats cliniques, il nous a fallu agir à plusieurs niveaux simultanément.

3.2.1. Au centre d'appel 18/112 : de la pédagogie incitative pour les opérateurs

Nous avons tout d'abord encouragé les opérateurs à déclencher l'application, dans son cadre d'emploi (AC en lieu et voie publique) de la manière la plus systématique possible. L'interfaçage des systèmes informatiques métier pompiers et de l'application Staying Alive n'a pas été possible. Pour un opérateur, les premières secondes de gestion d'un AC sont difficiles, chronométrées, ne laissant la place à aucune improvisation et dans un contexte de stress assez intense et imprévu, voire brutal (les appels pour AC représentent moins de 0,4% des appels). Le déclenchement de l'application n'a donc pas été confié à l'opérateur lui-même, mais à son chef de table. Ces chefs de table ne sont pas toujours disponibles et se sont vu rajouter une tâche dont ils n'ont pas tous saisi immédiatement la plus-value pour le patient.

Un vrai compagnonnage a été réalisé par toute l'équipe du Bon Samaritain au centre de prise d'appel, pour former, informer, motiver. Ensuite, pour gagner en nombre de déclenchement, les premières utilisations ayant trouvé un Bon Samaritain ont été mises à l'honneur en communication interne. Par la suite, les premiers déclenchements ayant permis à un Bon Samaritain de réaliser un massage cardiaque, puis ceux ayant permis une défibrillation ont connu la même diffusion. Nous avons essayé de donner des nouvelles des patients réanimés aux opérateurs pour susciter un renforcement positif. Nous avons pu, en particulier, leur diffuser

une bande audio d'appel téléphonique où l'utilisation de la cartographie des DSA de l'application permettait la délivrance d'un choc électrique. Sur cette bande était audible l'arrivée du DSA, les instructions de DSA puis, après le choc, le patient reprenant conscience (se plaignant qu'on lui appuyait sur la poitrine). Cette bande a été extrêmement efficace pour susciter l'adhésion, de même que la facilité de trouver un DSA avec la cartographie.

Certaines améliorations techniques ont été proposées par les chefs de tables. Par exemple, ils ont proposé d'appeler les Bons Samaritains ayant accepté une alerte pour les motiver et les guider. S'appropriant progressivement l'outil, et ayant l'impression que cela diminuait franchement leur relative impuissance face à des AC où le témoin ne savait pas masser, tout ceci a provoqué, progressivement une adhésion très importante et qui persiste depuis désormais 5 ans.

3.2.2. Une communauté de Bons Samaritains *: recruter le plus possible*

Initialement, les Bons Samaritains ont été constitués exclusivement de volontaires ayant bénéficié d'une formation aux gestes qui sauvent, quel qu'en soit le niveau. En effet, le commandement des pompiers de Paris, tout en assumant le poids juridique et politique d'une telle innovation voulait en diminuer le risque. Notre cible de recrutement a donc été davantage les secouristes et les soignants que le grand public.

Nous avons donc communiqué vers les pompiers, militaires et civils, à la retraite, en poste ou en formation ; vers les soignants, médecins et infirmiers de ville via leur ordre professionnel, mais également hospitaliers civils et militaires, internes et externes ; vers les secouristes, en poste dans une des grandes associations agréées de sécurité civile ou vers de simples citoyens ayant bénéficié d'une formation brève aux gestes qui sauvent.

Nous avons communiqué par affiches, calendriers pompiers, flyers, média traditionnels, réseaux sociaux, sites internet et congrès médicaux ou de secourisme. Nous avons développé un argumentaire simple et adapté à chaque public et à ses craintes spécifiques. Profitant d'une excellente relation avec l'équipe de la fondation « Bon Samaritain », nous avons fait développer un outil de suivi du nombre d'inscrits, pour quantifier, après chaque action de communication, le nombre de nouveaux Bons Samaritains.

L'action de communication la plus efficace a été la publication du témoignage, très émouvant, d'un patient d'une trentaine d'année survivant, massé et défibrillé par un Bon Samaritain avant l'arrivée des secours (figure 14) (221). Nous pensons avoir réalisé environ une centaine d'actions de communication différentes.

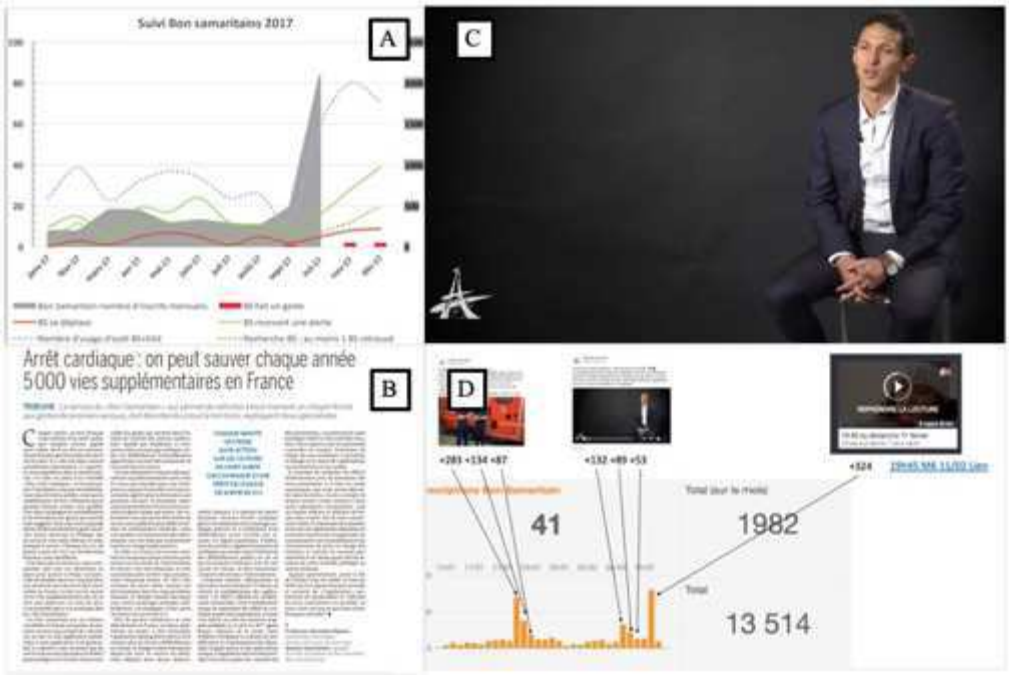

Figure 14: Communication interne pour les pompiers (panel A); Communication par voie de presse (panel B, journal Le Monde) ; Communication via les réseaux sociaux (panel C, vidéo du premier patient ayant bénéficié d'un Bon Samaritain et ayant survécu à son AC) ; Outil de suivi du recrutement des Bons Samaritains en fonction des actions de communication (panel D).

3.2.3. Amélioration de la cartographie des défibrillateurs et travaux non publiés

Conscients que l'outil « Bon Samaritain » s'appuyait tout autant sur une communauté nombreuse que sur une cartographie des défibrillateurs la plus exhaustive possible, nous avons demandé à tous les pompiers de Paris d'ajouter les DSA du secteur de leur caserne. Ils ont été encouragés à le faire au fil des DSA trouvés lors de leurs interventions, mais également de manière systématique lors de l'offrande des calendriers pompiers ou lors de « la quinzaine du DSA ». Enfin, les pompiers chargés de la prévention-incendie et réalisant les audits des établissements recevant du public ont été incités à intégrer les DSA sur l'application. En deux mois, 1 000 DSA sur les 5 000 référencés en zone d'intérêt ont été mis à jour (correction, ajout, suppression, enrichissement par photo ou numéro de téléphone de proximité par exemple).

En parallèle, nous avons été impliqués dans deux travaux sur les défibrillateurs publics, non publiés. L'un a consisté à calculer la distance de chaque AC de l'année 2017 du secteur BSPP avec le DSA public le plus proche pour savoir quelle proportion était utilisable avant l'arrivée des secours (figure 15). Dans ce travail préliminaire, qui ne prenait pas en compte l'accessibilité finale des DSA (interphone, portes fermées etc.), 42% des DSA publics auraient pu être utilisés

par un témoin faisant l'aller-retour à 6km/h avant l'arrivée des secours et 25% des AC se trouvaient à moins de 400 mètres d'un DSA public (distance avec trajet, non à vol d'oiseau). Ce travail a été réalisé et présenté par la Lieutenant de L'Espinay au congrès de la SFMU 2019. L'autre a été de suivre prospectivement le nombre de DSA publics utilisés, puisqu'il s'agissait du moment où de nombreux DSA sont arrivés dans l'espace public (équipement de la RATP, de certains taxis, de nombreuses sociétés etc.). Il a permis de monitorer l'effondrement de l'utilisation des DSA publics pendant le premier confinement COVID.

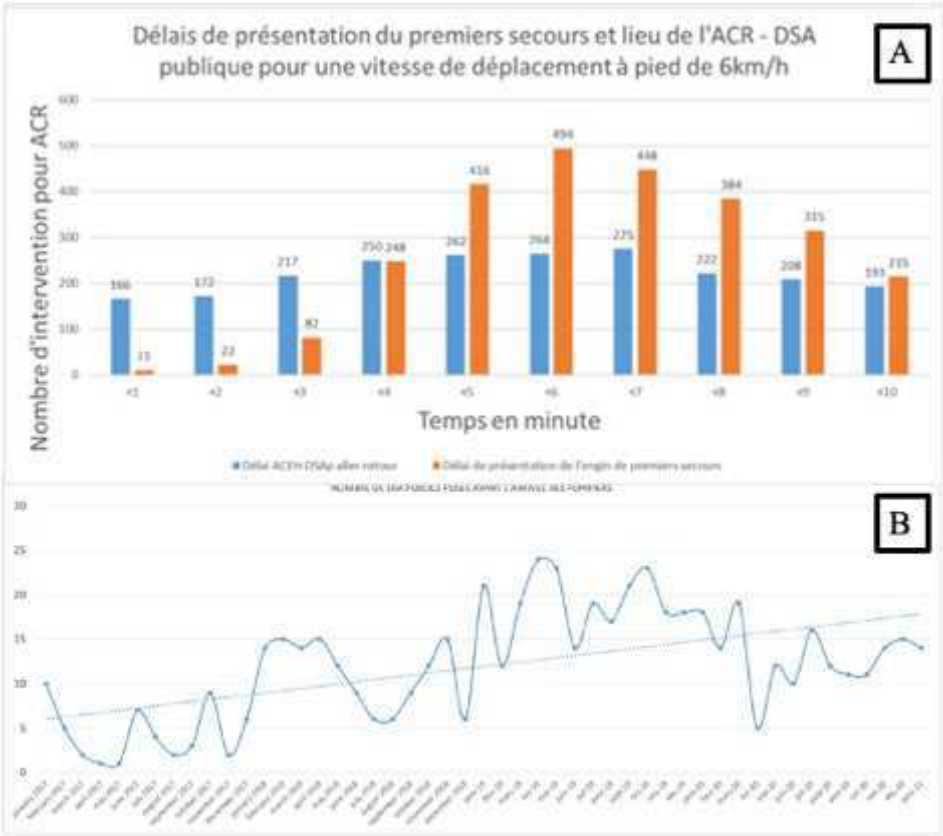

Figure 15 : deux travaux non publiés sur des sujets connexes de défibrillation avec des défibrillateurs publics. Panel A : proportion de DSA publics utilisables si un témoin va chercher le DSA public le plus proche avant l'arrivée des secours ; Panel B, Nombre de DSA publics utilisés dans le grand Paris de janvier 2017 à janvier 2021

3.2.4. Perfectionnement technologique

L'interface des Bons Samaritains a été progressivement modifiée pour laisser le choix entre une recherche simple de DSA (cas de AC à domicile où il n'a pas été envoyé de Bons Samaritains pendant les deux premières années) ou bien déclenchement de Bons Samaritains + recherche de DSA. Cette recherche a été améliorée en changeant l'icône des DSA qui disposent d'un téléphone fixe à proximité (possibilité de faire amener le DSA près du patient par un vigile de supermarché par exemple). L'affichage des Bons Samaritains acceptant l'alerte et leur suivi en temps direct a été affiné pour pouvoir les appeler et les guider en direct. Un mode collaboratif a été développé pour que plusieurs chefs de table puissent travailler sur la même intervention en se partageant les tâches.

De plus, une plateforme d'entraînement a été créée, pour permettre la formation initiale des opérateurs et leur entraînement régulier. Des questionnaires brefs après chaque déclenchement ont été créés tout à la fois pour les opérateurs et pour les Bons Samaritains (en fin d'étude), pour mesurer leur ressenti.

3.2.5. Recueil des données, méthodologie

Cette étude nous a fait utiliser, en vie réelle, une nouvelle modalité d'envoi de secours non institutionnels (compressions thoraciques et défibrillateurs). Nous n'avions, en début de pratique, aucune expérience du ressenti des Bons Samaritains, de leurs difficultés réelles, technologiques, médicales, éthiques, mais également parfois de leurs joies et de leur fierté. Nous avons donc décidé de rappeler tous les Bons Samaritains qui avaient reçu une alerte, qu'il l'ait acceptée ou non. Nous avons donc appelé environ 750 Bons Samaritains pour un entretien téléphonique guidé. Ce travail, hautement chronophage, nous a cependant donné une vision assez fidèle de ce que représentait, pour un citoyen ayant installé une application quelques jours ou quelques mois avant, la réception d'une alerte l'informant qu'une personne était en AC non loin d'elle. Le travail publié a pu mettre ainsi en avant, non seulement la corrélation entre survie et action effective des Bons Samaritains, mais également une description assez fidèle de qui ils étaient, et pourquoi ils avaient réussi, ou non, à arriver avant les secours.

3.2.6. Impact des résultats, reconnaissance des travaux

Ce travail a pu mettre en évidence que 18 Bons Samaritains avaient apporté et utilisé un défibrillateur avant l'arrivée des secours sur place pendant la première année d'utilisation. Si l'étude a été rétrospective et ne peut affirmer de causalité entre survie des patients en AC et action des Bons Samaritains, l'utilisation d'un score de propension a permis de rétablir une estimation causale avec une association de la survie avec l'intervention réussie des Bons Samaritains (adjusted OR vs. the control group = 5.9, 95% CI =2.12 to 16.54, p < 0.001) (Fig 16).

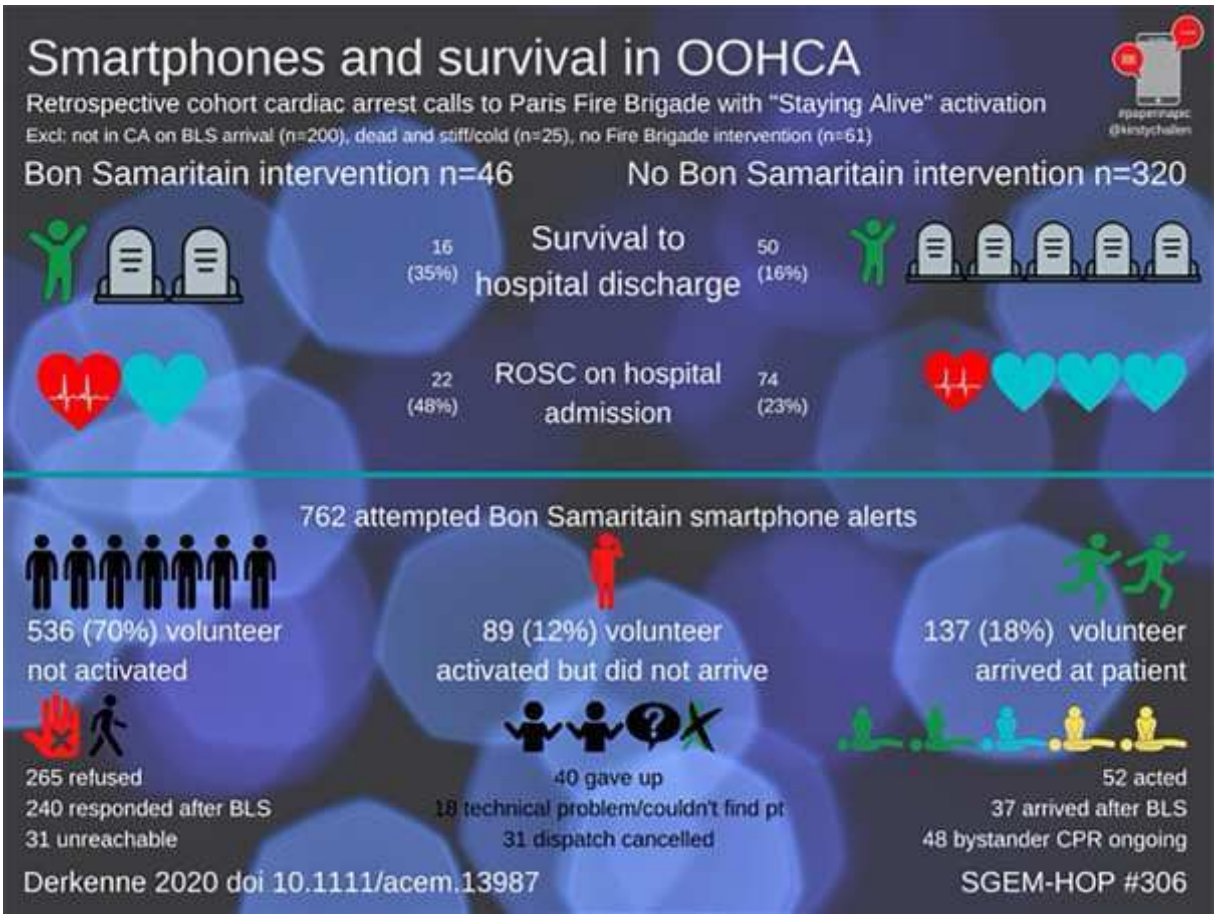

Figure 16: Création d'un visuel résumant notre travail, selon Morgenstern et al. (222).

A la suite de son utilisation en zone parisienne, l'application StayingAlive s'est déployée progressivement dans toute la France. Elle comptait, début 2024, 80 départements utilisateurs et 300 000 Bons Samaritains enregistrés dans l'application (dans notre zone, 5 600 en début de notre période d'étude et 23 000 en fin de période). En collaboration avec l'équipe de l'application, nous avons animé, au début, une communauté de médecins et de pompiers qui

implémentaient l'application dans leur département (création d'un drive avec des question opératives / communicationnelles / scientifiques ; requête et mise à disposition d'une analyse juridique sur les risques induits pour les SDIS par l'utilisation ou non de l'application etc.).

Notre centre a connu plusieurs évolutions depuis la publication de notre travail. Tout d'abord, ce travail a permis d'éclairer la hiérarchie de la BSPP sur l'intérêt du dispositif et sur les risques faibles pris par les Bons Samaritains. Ainsi, l'envoi des Bons Samaritains a été progressivement étendu aux AC en lieu privé, à l'exception des établissements de soins, des EPHAD, des AC traumatiques et des morts inattendues du nourrisson. Limitée aux seuls citoyens pouvant faire la preuve de leur formation aux gestes de premiers secours, l'application permet désormais à tous de s'inscrire, mais envoie préférentiellement les personnes formées pour masser quand ceux qui ne le sont pas sont dirigés pour apporter un DSA public.

Lors de la pandémie de COVID-19, une décision protectrice d'arrêt de la partie d'envoi de Bons Samaritains pour ne conserver que l'orientation des témoins vers les DSA référencés dans l'application a été initialement prise (219). Par la suite, l'envoi a été rétabli au prix d'une mention demandant au Bon Samaritain de certifier qu'il était équipé d'un masque.

Pendant ce travail, nous avons, bien sûr, réalisé une veille permanente de la bibliographie sur ce sujet, ce qui nous a conduit à publier une lettre (223) pour demander des précisions opérationnelles à des confrères anglais en cours de déploiement d'un système cousin : *PulsePoint* (224).

Pendant ce travail, et au titre de la connaissance que nous avions de ce sujet, nous avons été audité à l'Assemblée Nationale, avec deux autres membres de la *Cardiac Arrest Task Force des pompiers de Paris*, par la commission des lois constitutionnelles et de l'administration générale dans le cadre d'un projet de loi visant à lutter contre la mort subite et à sensibiliser la population aux gestes qui sauvent (199,225).

Ce travail a bénéficié d'un critique d'article dans la revue qui l'a publié (222). Il a été cité par 6 articles depuis sa publication (226–231).

3.3. Raccourcir la défibrillation via un drone porteur de défibrillateur

Nous avons réalisé une simulation numérique complexe pour mesurer l'intérêt de drones-défibrillateurs dans un centre urbain très dense. *Automatic external defibrillator provided by unmanned aerial vehicle (drone) in Greater Paris: A real world-based simulation* a été publié dans Resuscitation (209).

3.3.1. Méthodologie

Plusieurs constats ont été à l'origine de ce travail. Tout d'abord, en relisant les tracés des défibrillateurs publics, nous avons observé un nombre relativement élevé de pannes, ou de DSA non fonctionnels (15,35,196). De plus, de nombreux quartiers ne semblaient pas être équipés en DSA publics. Une littérature assez fournie commençait à publier des résultats de simulation de livraison de drone par DSA, mais négligeant de nombreux paramètres de la vie réelle. Enfin, aucune simulation ne s'intéressait à des centres urbains hyper denses comme l'est le grand Paris.

Nous avons donc réalisé, avec l'équipe de la Task Force, une simulation utilisant au maximum des paramètres de la vraie vie : taux de détection des AC, météo, impossibilité pour un témoin seul à domicile d'arrêter les compressions thoraciques pour aller chercher un DSA déposé par un drone etc. Le délai mis par un drone-DSA simulé a été comparé au délai réel des secours sur une base de données.

3.3.2. Impact des résultats, reconnaissance des travaux

Ce travail a permis d'établir qu'environ un quart des AC pourrait bénéficier d'un drone-DSA avant l'arrivée des secours. Conscients des limites de la méthodologie en simulation et certains que les premières expérimentations viendraient bousculer certains paramètres que nous avions simulés, ce travail a été l'occasion de créer un site internet, où la simulation peut être jouée, en comparant deux simulations aux paramètres différents pour en mesurer l'impact. De même, il est possible, pour une autre équipe de recherche, d'y intégrer ses propres paramètres pour bénéficier de l'algorithme (position des AC, position des bases drones etc.).

Cette publication a eu un double effet. Elle a convaincu les dirigeants de la BSPP de l'intérêt des drones, et a motivé une équipe qui a commencé à réaliser leur mise en œuvre. S'il existe des process techniques et opérationnels à affiner, la technologie de drone autonome est au point

et a donc pu être testée dès l'été 2022 à Paris. La réglementation étant extrêmement contraignante à Paris, les premiers essais ont donc concerné des survols autonomes de la Seine, avec recherche automatique de noyés simulés et largage de bouées. L'équipe drone-BSPP a obtenu des financements assez intéressants (France Relance, Jeux Olympiques) pour continuer à se développer. Une collaboration assez naturelle a été lancée avec le SAMU 94, en charge des ambulances volantes (projet APHP, Aéroports de Paris). Notre article a été cité 12 fois depuis sa publication (231–243).

3.4. Accélérer la reconnaissance et la défibrillation des fibrillations récidivantes

Nous avons implémenté un nouvel algorithme de défibrillation dans les défibrillateurs des équipes de premiers secours des pompiers de Paris. Nous avons comparé les données de défibrillation, des données rythmiques et de survie à une cohorte historique. *Analysis During Chest Compressions in Out-Of-Hospital Cardiac Arrest Patients, A Before/After Study: The DEFI 2022 Study*, a été soumis pour publication le 16 mars 2024 à Circulation.

3.4.1. Méthodologie

Dans un travail préalable du Groupe de Travail sur l'Arrêt Cardiaque des pompiers de Paris, il a été mesuré que 50% des patients en arrêt cardiaque recevant un choc en recevrait au moins un deuxième pendant leur réanimation. Ceux qui récidivaient le faisaient presque tous dans la minute qui suivait la délivrance d'un choc (25 [13-44] secondes) (48). Dans une chronologie compatible, Schiller SAS, s'appuyant sur ses travaux d'analyse du rythme électrique per massage a obtenu la Norme Française pour son algorithme Analyze Whilst Compressing (AWC) capable de raccourcir la phase de réanimation cardiopulmonaire à 1 minute en cas de rythme chocable détecté (162). Nous avons donc réalisé une étude de type avant/après, comparant les caractéristiques de la réanimation par les pompiers (quantité de compressions thoraciques délivrées, via le Chest Compression Fraction…), les données électrocardiographiques des patients (temps passé dans chaque rythme électrique) et la survie de deux cohortes. La cohorte « avant » comprenait les patients de la première année où les nouveaux défibrillateurs DGT7 avaient été mis en dotation dans les engins de secours ; la cohorte « après » comportait les premiers patients bénéficiant de l'AWC.

Il s'agit d'une étude ayant demandé un investissement très important, mais ayant permis la mise en œuvre de compétences nouvelles : soumission à un Comité de Protection des Personnes et utilisation de ClinicalTrial.gov, utilisation du logiciel Prism etc.

3.4.2. Impact des résultats, reconnaissance des travaux

Tout d'abord, cet algorithme nous a démontré que les pompiers s'adaptaient à un nouvel algorithme proposant des cycles variant entre 1 et 2 minutes de manière imprévisible sans altérer les gestes de réanimation qu'ils délivrent. Préalablement à l'étude DEFI 2022, nous avions réalisé une étude de *usability* qui avait été rassurante, cependant nous avons confirmé ce résultat avec l'étude DEFI 2022.

Ensuite, l'utilisation de l'AWC a été associée à une amélioration de nombreux paramètres indirectement liés à la survie : gain de 5 points de CC*f* , mais également amélioration des temps pré et post choc, diminution du temps total passé en fibrillation ventriculaire au profit d'asystolie et de rythme organisé à parts égales. L'analyse principale ne montrait pas d'amélioration de la survie pour les patients ayant bénéficié de l'AWC. Cependant une analyse en sous-groupe avec des patients en « phase électrique » retrouvait une association entre utilisation de l'AWC et survie

Cette étude a permis, enfin, de résoudre un des *critical knowledge* identifié par l'AHA : "whether artifact-filtering algorithms for ECG rhythm analysis during CC in a real-time clinical setting could decrease pauses in CC and improve outcomes". Cet article a été présenté aux congrès 2023 de l'AHA et de l'ERC.

3.5. Améliorer la défibrillation manuelle

Nous avons réalisé une étude prospective multicentrique en simulation sur la performance de médecins préhospitaliers pour reconnaître des rythmes électriques d'AC. *Assessment of emergency physicians' performance in identifying shockable rhythm in out-of-hospital cardiac arrest: an observational simulation study* a été publié dans le journal Emergency Medical Journal (210).

3.5.1. Méthodologie

Nous avons conduit ce travail, ayant constaté l'hétérogénéité de la reconnaissance des rythmes électrique per AC des médecin préhospitaliers, qui pratiquent quasiment exclusivement une défibrillation manuelle lors de leurs AC, cette dernière étant réputée obtenir une pause pré-choc plus courte (244). Un travail préalable avait déjà été réalisé, 15 ans auparavant, par la Cardiac Arrest Task Force des pompiers de Paris, mais sa méthodologie ne permettait pas la mesure des délais de décision ; de même il permettait aux sujets étudiés de regarder l'ensemble du tracé électrocardiographique en même temps (245). Pour permettre davantage de réalisme dans la simulation numérique qui constitue l'ossature de la méthode d'évaluation, un site internet simulant un défibrillateur manuel a été construit.

190 médecins de 6 services d'urgence préhospitalière différents ont répondu s'ils pensaient que les 60 tracés qui leur étaient proposés successivement étaient, ou non, chocables.

3.5.2. Impact des résultats, reconnaissance des travaux

Ce travail a permis de mesurer la sensibilité et la spécificité des médecins préhospitaliers. Ceux-ci semblent capables de détecter la plupart des rythmes chocables, en environ 2 secondes, cependant leur spécificité est moins bonne. La proportion de rythmes non chocables désignés à tort comme devant bénéficier d'un choc était assez importante. Si, pour les asystolies, une confusion avec la fibrillation petite maille peut être assez classique il n'en va pas de même avec les PEA. La spécificité pour ne pas choquer les PEA était basse, de 0,83 [0,72 à 0,86].

Nous avons été surpris par le nombre de participants qui a demandé à pouvoir accéder à ses résultats. Nous ne l'avions pas prévu initialement, mais nous avons fait développer une version du site internet consacrée à l'entraînement des praticiens qui le souhaitaient. Ce faisant, nous avons réalisé un des résultats importants de ce travail. Au-delà de la mesure globale de la

performance des médecins préhospitaliers, il peut être intéressant que chaque médecin connaisse sa propre performance (vitesse, sensibilité, spécificité) pour choisir en connaissance de cause de pratiquer la défibrillation manuelle ou semi-automatique en pratique clinique.

L'éditorial de la revue dans laquelle il a paru lui a été consacré (246). Deux travaux cousins ont été menés sur le même simulateur : une thèse de médecine générale a été consacrée à la mesure de la performance de médecins généralistes militaires et de médecins correspondants SAMU (247), un article a été réalisé sur la mesure des médecins anesthésistes (248).

4. DISCUSSION, PERSPECTIVES

Favoriser une défibrillation précoce est fortement associé à la survie, tout en restant une gageure. Notre approche explore bien les difficultés de chaque maillon intervenant pour permettre tout d'abord l'accès rapide des patients à un défibrillateur puis l'optimisation de l'utilisation et du fonctionnement de celui-ci pour que chaque rythme chocable se voit délivrer un choc au plus tôt.

4.1. En centre d'appel : dépister, faire défibriller, envoyer le(s) DSA les plus rapides

Les actions en centre de réception des appels d'urgence sont sans doute celles qui ont le plus d'impact sur la survie des patients, tels que le rapporte Deakins et al. dans sa chaîne aux maillons de taille décroissante (88).

Notre travail de dépistage des AC au téléphone s'articule tout à fait avec notre étude sur l'envoi de Bons Samaritains. Cela concerne à la fois les centres d'appel et un de leurs effecteurs naturels : les témoins et les citoyens volontaires. Par exemple, l'étude *DISPATCH*, qui vient de finir ses inclusions dans plusieurs SAMU s'intéresse à la fois à la formation des assistants de régulation du SAMU au dépistage des AC et utilisation de SAUVLIFE, application de citoyens sauveteurs (249). Ces deux modifications sont introduites simultanément dans le but principal d'améliorer le taux de patient en AC recevant des compressions thoraciques en cours à l'arrivée des secours. Un objectif secondaire de cette étude est le taux de patients avec un défibrillateur avant l'arrivée des secours.

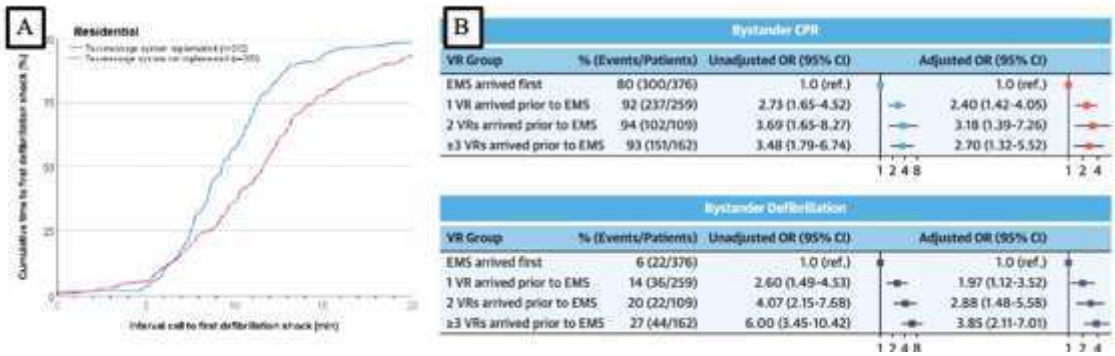

Figure 17: Implémenter une solution de citoyens sauveteurs réduit le délai effondrement-défibrillation (panel A, selon Stieglis et al. (250)); plus le nombre de citoyens qui acceptent l'alerte est élevé, plus ils arrivent nombreux avant l'arrivée des secours, plus souvent le patient est défibrillé avant l'arrivée des secours (panel B, selon Gregers et al.(251))

Ces deux avancées arrivent dans une phase de maturité. Par exemple, les applications de citoyens sauveteur sont passées de la question « faut-il le faire ? » à l'affirmation actuelle « il faut le faire ». Les axes de recherches reposent désormais sur l'optimisation de ces applications. Un article de 2023 rapporte que la réussite de la défibrillation avant l'arrivée des secours est associée au nombre de citoyens volontaires qui acceptaient l'alerte (Figure 17) (251). Un autre, de 2022, rapporte une réduction du délai au premier choc lors de l'introduction d'une application de citoyens sauveteurs dans une communauté (250). Les recommandations de la SFMU de 2024, en cours de publication, sont également la preuve d'un sujet important pour la communauté de médecine d'urgence, et pour laquelle des avancées récentes nécessitent que des bonnes pratiques soient clarifiées.

Pour le dépistage des AC, les voies d'avenir sont multiples, médicales ou non (figure 19). Elles visent le gain de vitesse de défibrillation, mais pas uniquement ; par exemple :

- de très nombreux objets connectés pourraient techniquement aider à la détection des AC : caméras intelligentes dans l'espace public voire privé, montres connectées etc. Par exemple, certains défibrillateurs implantables (ou portables tels la LifeVest de Zoll ® (252)), en cas de délivrance de choc, se connectent au smartphone du patient et envoient des alertes aux équipes de soins. Les questions éthiques et légales que cela soulève restent intactes ;
- la géolocalisation immédiate des appelants en centre d'appel est un gain de temps formellement identifié dans 95% des appels de notre travail sur la détection des AC, dans sa table 3. Une solution techniquement au point depuis longtemps - mais dont la diffusion tarde - devrait voir le jour à court terme (Advanced Mobile Location) (253) ;
- nous manquons de données pour savoir s'il faut conseiller de mettre en position latérale de sécurité les patients rapportés par le témoin comme inconscients mais qui respirent (bénéfice de la limitation de la ptose du massif laryngé versus retard au diagnostic des AC méconnus initialement ?) ;
- la visioconférence est désormais disponible via les caméras des smartphones et dans les régulations, mais les données manquent pour savoir s'il faut ou non dépister via visiorégulation ;
- des technologies capables de dépister les bruits émis par les *gasps* ou de l'intelligence artificielle conversationnels sont en cours d'élaboration, non effectifs encore actuellement mais pourraient le devenir (254,255) ;

- les pompiers de Paris se sont longtemps posé la question de guider les compressions thoraciques des témoins en leur envoyant une boucle de film de quelques secondes. Cette idée, prometteuse pendant des tests en simulation n'a cependant pas été déployée ;
- la mesure simple du taux d'AC dépisté en centre d'appel est une vigie exigeante, intrinsèquement porteuse d'amélioration. Sa mesure exacte ne peut reposer que sur l'écoute des bandes téléphoniques, comme nous avons procédé. Il s'agirait, cependant, d'un travail fastidieux et trop long pour être mené en continu. Les pompiers de Paris ont mis en place un indicateur imparfait mais assez habile. Au dénominateur, le nombre d'arrêt cardiaque pris en charge est dénombré par déclaration des VSAV de manière très fiable (dans leur rapport d'intervention obligatoire, l'utilisation d'un défibrillateur est une variable correctement renseignée). Au numérateur : nombre d'AC pour lesquels le SMUR est déclenché avant que le premier VSAV déclenché ne se soit présenté à domicile. Il existe, bien sûr, des faux positifs au numérateurs mais cette approximation reste constante.
- Au moment de mettre cette thèse sous presse, le *preprint* ILCOR 2024 a été publié. Il s'intéresse, pour la première fois semble-t-il au *dispatcher-assisted public-access AED* : le niveau de preuve de cette pratique reste insuffisant ; un risque réel de réaliser la recherche de DSA en centre d'appel est de parasiter le lien entre le témoin qui réalise des gestes et l'opérateur du 15-18 qui le guide, en altérant la réalisation *t-CPR* (256). Nous avions évoqué ce sujet dans notre travail de dépistage des AC, et pensons avoir limité ce risque en déléguant une grande partie de la recherche du défibrillateur aux citoyens sauveteurs plutôt qu'au requérant téléphonique ;

Pour les citoyens sauveteurs, les évolutions possibles sont, par exemple (figure 18):

- a minima de continuer à recruter des citoyens sauveteurs ; mieux cartographier les défibrillateurs de l'espace public, voire leur transmettre directement l'alerte ! Le concours Lépine 2022 a ainsi récompensé « géocoeur » : il s'agit d'un dispositif qui est fixé sur les défibrillateurs de l'espace public. En cas d'arrêt cardiaque à proximité, les secours sont en mesure de le faire sonner et d'y allumer une vive lumière, permettant aux passants à proximité d'être alertés, de se saisir du défibrillateur, et, via un QR code, de trouver l'emplacement de l'arrêt cardiaque (257). Ceci peut également être utilisé pour faciliter le repérage puis la récupération des DSA par les Bons Samaritains lors de leur trajet vers l'emplacement de l'arrêt cardiaque ;
- l'intégration des applications aux systèmes informatiques natifs des SAMU (e avec SI-SAMU) et des pompiers (prévu avec le système NEXSIS en 2024) ;

- l'interconnexion entre les différentes applications existantes, a minima les françaises (SAUVLIFE, STAYINGALIVE et, dans une moindre mesure, PERMIS DE SAUVER). Cela paraît cependant pour l'instant bloqué, pour des raisons de rivalité historique, de culture, de type de fonctionnement, de technologie voire de doctrine d'emploi des citoyens sauveteurs ;
- potentiellement le recrutement de citoyens sauveteurs équipés par les pouvoirs publics de défibrillateurs (taxis, policiers, voire simples citoyens). Une expérimentation, à Angers, en 2023-2024 a équipé 50 « super citoyens sauveteurs » avec des défibrillateurs qu'ils pouvaient emporter avec eux dans leur vie privée. Ils étaient référencés et déclenchés via l'application SauvLife. Les résultats préliminaires sont très encourageants (5% des AC bénéficient d'un DSA public posé avant l'arrivée des secours si aucun dispatch de citoyens sauveteurs, 13% si des citoyens sauveteurs de SauvLife arrivent avant les secours, et 67% en cas de « super citoyens sauveteurs ») (258,259).

Pour envoyer un défibrillateur :

- les drones-DSA sont une réalité puisqu'un premier défibrillateur a été déployé et utilisé chez un patient, en Suède. Seules les réglementations européennes puis françaises et l'implémentation opérationnelle restent à accomplir. Il s'agit, cependant, d'obstacles probablement plus difficiles que la technologie, qui semble mature ;
- avec une technologie plus simple et immédiatement disponible : depuis quelques mois, à Paris, les VSAV disponibles de retour d'intervention ou en transport hôpital de patients non graves peuvent être détournés pour les AC. Cela s'effectue, sans géolocalisation, via un appel radio général. L'évaluation de l'efficacité de ce système sera conduite dans les mois à venir ;
- les *Public Access Defibrillation program* ne sont pas encore assez intriqués avec l'organisation légale et sociale de nos communautés. Les lois imposent depuis peu de temps des défibrillateurs dans les établissements recevant du public. Cette obligation pourrait, par exemple, être étendue pour viser un maillage de 200 mètres dans les grands centres urbains, à l'instar des bouches et des poteaux incendie.

Ces perspectives doivent être prises avec les précautions qui s'imposent, des ruptures technologiques étant possiblement à même de venir bouleverser les idées présentées (ultra miniaturisation de défibrillateur, modèles prédictifs de la survenue des AC par exemple), voir figure 19.

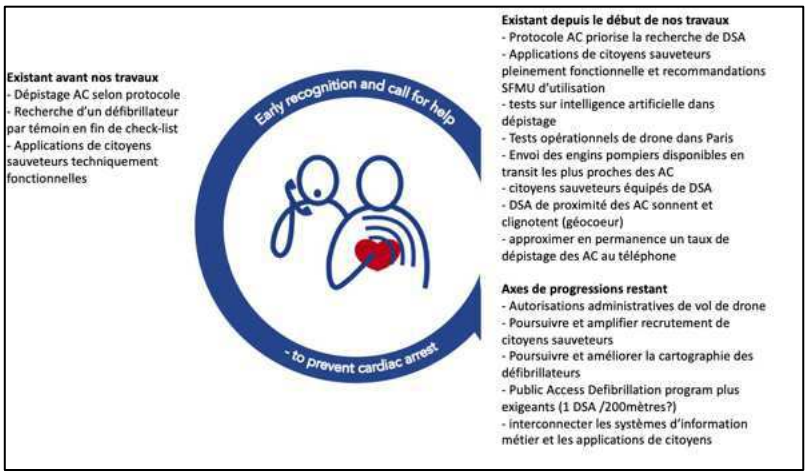

Figure 18: synthèse des avancées sur l'AC en centre d'appel

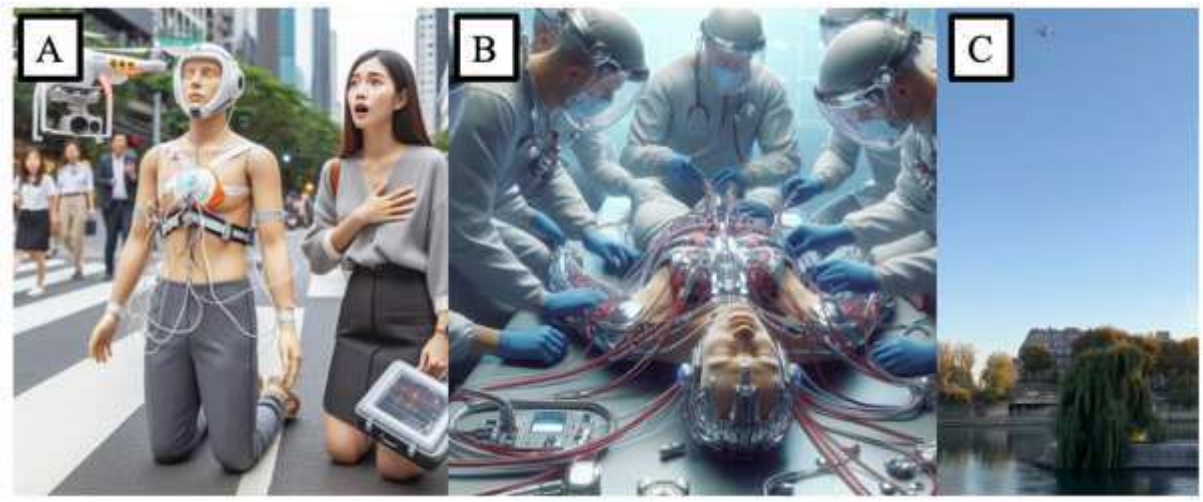

Figure 19: nous avons demandé à Bing Image Créator, une intelligence artificielle de générer deux images de la prise en charge des arrêts cardiaques en 2100. Il semble considérer les drones comme un futur possible…

4.2. Au chevet du patient, améliorer la performance de tous pour défibriller mieux et plus vite

4.2.1. Comparaison à la littérature pour les analyses per massage

Notre travail sur l'AWC répond à un des *knowledge gap* de l'ILCOR. Il s'inscrit dans la lignée des améliorations successives qui ont fait progresser les défibrillateurs pour limiter les risques et améliorer les gains du pari évoqué en 1.4.2.1.. Il a permis de valider la technologie d'analyse *per massage*, d'en affirmer le caractère sans danger et d'identifier une sous population d'AC précoces qui pourraient en bénéficier pour un gain de survie. Il s'agit du deuxième travail sur les algortithmes d'analyse per massage de la littérature. Le premier, publié par de Graaf et al. concernait l'algorithme CPRinsight (Stryker ©)(163). Ce dernier utilise les analyses *per massage* afin de supprimer les analyses *hors massage* toutes les 2 minutes. Il s'agissait donc d'avantage d'augmenter le CCF des patients en rythme non chocable que de raccourcir le temps passé en fibrillation. La performance de leurs analyses per massage était globalement comparable à celle de l'AWC, ou un peu meilleure. Cependant, contrairement à l'AWC, leur algorithme comportait 3 issues possibles :

- rythme chocable détecté per massage => conduite d'une analyse hors massage puis choc ;
- rythme non chocable détecté per massage => annulation de l'analyse hors massage, par conséquent phase de RCP de 4 minutes ;
- absence de certitude sur le rythme détecté => conduite d'une analyse hors massage classique. Cette issue était retrouvée dans 14% des cas en cas de VF sous-jacente, dans 22% des cas en cas de rythme organisé et dans 38% des cas en cas d'asystole ;

L'AWC, avec ses deux issues (chocable/non chocable) et qui vise à raccourcir les phases de CPR peut donc difficilement être comparée au CPRInsight avec ses trois issues (chocable, non chocable, ne sait pas) et qui vise à supprimer les phases d'analyse toutes les 2 minutes. Nous pouvons cependant rapprocher ces deux algorithmes sur le plan de leur performance.

4.2.2. Comparaison à la littérature pour l'examen de la défibrillation manuelle des médecins

Curieusement, notre travail d'évaluation sur simulateur de la performance des médecins est le seul n'ayant jamais été cité depuis sa publication, hors l'éditorial qui lui a été consacré (246). Les performances des médecins pour défibriller semblent donc être un angle mort de la

recherche, alors que notre travail identifiait que 57% des médecins préféraient la défibrillation manuelle à celle automatique… et que les pratiques semblaient pour le moins perfectibles.

Le travail sur l'étude de la performance des médecins a été conduit en simulation. Une étude de pratique rétrospective sur la sensibilité, la spécificité et la vitesse de décision des médecins ne peut être réalisée de manière rétrospective. Dans les tracés de défibrillateurs, parmi les nombreux moments sans délivrance de compressions thoraciques, il n'est pas possible d'identifier avec certitude les périodes d'analyses réalisées par les équipes médicales. En revanche, à l'avenir, nous pourrions concevoir une étude qui verrait les équipes médicales randomiser entre la conduite d'une réanimation avec un DSA ou avec un défibrillateur manuel.

4.2.3. Perspective pour les DSA

Plusieurs fonctions ne sont pas réalisées par les défibrillateurs. Elles sont pourtant techniquement possibles, certaines concernant (ou non) la réduction du temps passé en fibrillation :

- les DSA ne réalisent pas d'électrostimulation, inefficace sur les asystolies (260). En revanche, ils ne sont pas conçus pour détecter les ondes P et ne réalisent pas d'électrostimulation sur les asystolies porteuses d'onde P, quand bien même il est recommandé d'essayer de les électro-entraîner (62). Il pourrait s'agir d'une avancée intéressante, puisqu'alors, le défibrillateur ne se consacrerait plus uniquement aux rythmes chocables ;
- les DSA ne proposent pas d'annonce vocale suggérant de vérifier la bonne position des électrodes en cas de récidive/persistance de la VF après de multiples chocs délivrés. Il s'agit pourtant d'une cause classique d'échec de défibrillation (l'électrode latérale gauche étant trop antérieure, voire 1.4.1.1.).
- les défibrillateurs ne dépistent pas les RACS. Ils pourraient le réaliser via plusieurs techniques :
    - dans notre travail sur l'AWC, nous avons défini la fin de fenêtre d'observation sur des critères que pourrait partiellement analyser un DSA : QRS physiologiques, à une fréquence compatible avec une RACS, avec une contraction de la courbe d'impédance thoracique signant un mouvement cardiaque contemporain du QRS (261,262) ;
    - ce dépistage de RACS pourrait tout à fait être réalisé via un capteur de $Sp0_2$: la détection d'une saturation pulsée en l'absence de détection de compression

thoracique via l'impédance signerait une onde de pouls palpable. Cela serait sans doute assez peu sensible, mais très spécifique ;

- des capteurs échographiques placés en regard des carotides pourraient également aider à cette détection de RACS ou à guider la qualité des compressions thoraciques (263), de même la mesure de l'$EtCO_2$ pourrait y contribuer (264);
- le dépistage automatique des RACS pourrait limiter la délivrance de compressions thoraciques post RACS qui, si elles sont associées à la survie, sont également associées à la récidive des fibrillations ventriculaires. Actuellement les secouristes n'ont le droit d'arrêter la délivrance des compressions thoraciques qu'en cas de réveil franc du patient, avec paroles et mouvements en l'absence de compressions thoraciques

- aucun DSA n'est actuellement capable de réaliser une double défibrillation séquentielle. Il convient donc, pour l'opérateur, de disposer de deux défibrillateurs et d'assurer lui-même la conduite de l'analyse puis la délivrance successive des chocs. Le meilleur délai entre la délivrance des deux chocs n'est pas connu. Les intrications de la double défibrillation avec les thérapeutiques intraveineuses ou les formes d'ondes sont également une voie de recherche ;
- chaque analyse de DSA est, algorithmiquement, complètement indépendante des analyses précédentes. Le DSA est également aveugle du genre, l'âge et les antécédents du patient. Il s'agit d'un champ important qui pourrait connaître des avancées notables, avec des DSA capables de prédire le succès d'un choc en fonction, par exemple, du résultat de chocs préalables, ou en fonction de l'évolution de l'aspect de la fibrillation ventriculaire. Il existe déjà, dans la littérature, des paramètres permettant de prédire le succès d'un choc (aire sous la courbe de fibrillation)(265). En effet, actuellement, il reste possible pour un défibrillateur de délivrer une quinzaine de chocs en quinze analyses, quand bien même ces chocs n'entraînent jamais de changement de rythme sous-jacent (fibrillation réfractaire ou erreur systématique d'un défibrillateur leurré par un pacemaker par exemple). Ces paramètres pourraient être intégrés à la décision choc/pas choc pour optimiser le nombre de chocs et la précocité du RACS.
- les DSA ne disposent pas de mode « secouriste professionnel » où les annonces vocales seraient réduites au minimum ;
- aucun algorithme de DSA n'est actuellement conçu pour s'adresser à des médecins en proposant une aide à la détection de causes curables (alternance électrique et

tamponnade liquide ou gazeuse, onde J d'Obsorbn et hypothermie par exemple) (266). De même, un DSA s'adressant aux experts pourrait faire bénéficier d'analyse sous massage (impossible à l'œil nu pour des experts regardant le tracé du scope) et offrir aux experts la possibilité de choquer dès le début d'une phase d'analyse sans massage, cette analyse étant souvent plus rapide pour l'œil de l'expert que pour le DSA ;

- les DSA ne communiquent pas avec les autres appareils médicaux (respirateur, pousse-seringue, planche à masser), alors qu'un certain nombre d'interactions pourraient être intéressantes, a minima pour disposer sur un seul tracé de l'intégralité des données de réanimation.

Nous sommes à un moment charnière pour les DSA avec l'arrivée de technologies d'analyses *per massage* de sensibilité et spécificité suffisantes pour proposer des compressions thoraciques continues sans aucune période dédiée à des phases analyses sans massage. A l'extrême, avec un tel système, et pour un patient bénéficiant d'un dispositif de délivrance automatisé des compressions thoraciques et ventilé grâce à un respirateur, nous pourrions imaginer une réanimation avec *CCf* à 100%. Ce patient bénéficierait de compressions thoraciques en continu, d'analyse sous massage en continu ; il pourrait également être défibrillé sans interruption de massage, au moment le plus opportun du cycle compression décompression mais également uniquement si la probabilité de cessation de la VF est assez élevée.

5. CONCLUSION

S'intéresser à raccourcir le délai à la défibrillation est, par nature, se pencher sur toutes les occasions où le cœur d'un patient fibrille, et un choc électrique n'est pas délivré immédiatement.

Certaines pistes que nous avons explorées étaient balbutiantes au début de nos travaux (citoyens volontaires, défibrillation guidée en centre de réception des appels d'urgence) et sont désormais une pratique courante. Nos travaux ont contribué à augmenter le niveau de preuve scientifique de leur intérêt.

D'autres travaux semblent moins novateurs (la mesure de la performance des médecins pour défibriller) mais sont pertinents en termes d'analyse des pratiques, surtout à l'heure où les DSA deviennent de plus en plus performants et où l'abandon de la défibrillation manuelle est une question de pratique clinique.

Enfin, d'autres approches sont extrêmement innovantes. Pour le drone, notre travail a été en partie à l'origine du programme de drones autonomes des pompiers de Paris. Nous sommes ainsi passés d'une simulation numérique à des vols réels. L'algorithme AWC, dont le travail d'évaluation vient d'être soumis pour publication est le deuxième à s'intéresser à l'analyse sous massage, et le premier à proposer un délai de phase de RCP variable. Il s'agit donc d'une révolution puisque le défibrillateur, au lieu de proposer une réponse de type OUI/NON à une question systématiquement posée toutes les deux minutes, est désormais capable d'ajuster ce délai… et ce, avec des résultats cliniques intéressants. Il ne s'agit, bien sûr, que d'une première évolution puisque de nombreuses évolutions algorithmiques sont encore possibles pour délivrer un choc le plus efficacement possible, c'est à dire sans pause superflue, au plus vite dès la refibrillation, avec une probabilité de cessation de VF élevée.

Ces travaux ont tous été réalisés chez les pompiers de Paris. Il est certain que l'incidence élevée des AC pour cette structure (10/jours), la présence d'une cellule scientifique et l'ancienneté des travaux sur l'AC conduisent à une vision relativement technophile, avec des secouristes très performants et pour des délais d'intervention réduits. Les problématiques des AC en zone rurale sont probablement un peu différents. Des solutions peuvent cependant être utiles tant pour les « AC des villes » que pour les « AC des champs », les drones par exemples. Des considérations éthiques, sociologiques et financières sont également d'importance pour une prise en charge optimisée des patients sur l'ensemble des territoires de santé.

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7. ARTICLES

7.1. Efficiency of a Global System with a New Method of Detection.

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Clinical paper

Improving emergency call detection of Out-of-Hospital Cardiac Arrests in the Greater Paris area: Efficiency of a global system with a new method of detection

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Abstract

Aim: The detection of cardiac arrests by dispatchers allows telephone-assisted cardiopulmonary resuscitation (t-CPR) and improves Out-of-Hospital Cardiac Arrest (OHCA) survival. To enhance the OHCA detection rate, in 2012, the Paris Fire Brigade dispatch center created an original technique called "Hand On Belly" (HoB). The new algorithm that resulted has become a central point in a broader program for dispatch-assisted cardiac arrests.

Methods: This is a repeated cross-sectional study with retrospective data of four 15-day call samples recorded from 2012 to 2018. We included all calls from OHCAs cared for by Basic Life Support (BLS) teams and excluded calls where the dispatcher was not in contact directly with a witness. The primary endpoint was the successful detection of an OHCA by the dispatcher; the secondary endpoints were successful t-CPR and measurements of the different time intervals related to the call. Logistic regressions were performed to assess parameters associated with detecting OHCAs and initiating t-CPR.

Results: From 2012 to 2018, among the detectable OCHAs, the proportion correctly identified increased from 54% to 93%; the rate of t-CPRs from 51% to 84%. OHCA detection and t-CPR initiation were both associated with HoB breathing assessments (adjustedOR: 89, 95%CI: 31−299, and adjustedOR: 11.2, 95%CI: 1.4−149, respectively). Over the study period, the times to answering calls and the time to sending BLS teams were shorter than those recommended by international guidelines; however, the times to OHCA recognition and starting t-CPR delivery were longer.

Conclusions: The HoB effectively facilitated OHCA detection in our system, which has achieved very high performance levels.

Keywords: Cardiac arrest, Telephone cardio-pulmonary resuscitation, Dispatch-assisted cardiopulmonary resuscitation

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Introduction

During an Out-of-Hospital Cardiac Arrest (OHCA), each link in the survival chain has an impact on the patient's outcome and allow one to continue to the next link until survival is achieved. The first link, "early recognition of OHCA", is probably the most crucial.[1] In France, the incidence of OHCAs is about 50/100,000 inhabitants/year. Although 30−40% of the population has received at least one training session in first aid, less than 10% of bystanders recognize OHCAs prior to the call for help.[2–5]

In the literature, dispatcher-assisted cardio-pulmonary resuscitation (DA-CPR) combines cardiac arrest (CA) detection and telephone-assisted cardio-pulmonary resuscitation (t-CPR). It increases the OHCA detection rate and the likeliness that chest compressions (CC) will be performed by bystanders until the arrival of the basic life support team (BLS). Indeed, bystander, whatever his level of first aid knowledge, can limit the time spent without no-flow and reduce OHCA mortality.[5–10] This progress was associated with the successful implementation of various actions by the DA-CPR program, including: revised protocols, training, and quality improvement.[11]

Training and quality assessments of all emergency calls have been strengthened in the Paris Fire Brigade call center since 2011. In addition, the method for evaluating the respiratory status of an unconscious patient has been modified. The American Heart Association (AHA) recommends that the dispatcher asks the caller: "Does the victim breathe normally?". The effectiveness of this question is associated with a low level of evidence. In the literature, we did not find any other method for detecting CA.[12,13] With the "Hand on Belly" (HoB) method, the Paris Fire Fighters Dispatch Center invented an objective, simple, reproducible tool for assessing respiratory status in a relevant way. In this technique, the dispatcher asks the caller to places his/her hand on the victim's belly. Each time the belly rises, the caller says “TOP” on the phone. The time interval between two “TOPs” is taken to estimate the ventilation frequency. Based on the threshold value chosen, the caller is told to start CCs. The HoB was implemented in 2011 and was first evaluated by Travers et al. and showed positive results.[4]

The purpose of this study was to assess performance improvement in a DA-CPR program over the period of 2012 to 2018. Additionally, we compared features of the DA-CPR program to those of the 2016 AHA guidelines, including OHCA detection, the t-CPR rate, and time interval compliance.

Methods

Dispatch center organization

The Paris Fire Brigade dispatch center is the largest Public Safety Answering Point (PSAP)/Emergency Medical Dispatch (EMD) in France and one of the most important in Europe. It is responsible for an area of 800 km^2 with 7 million inhabitants; it dispatches 1400 Basic Life Support (BLS) teams and 75 Emergency Medical Support teams per day.[14] Since 2016, emergesncy calls have been routed through a common answering platform for firefighters and police officers, with a two-step call management system; this replaced the previous one-step system. First, the PSAP operator screens 14,500 calls/day and allows 3100 specific requests for assistance to pass to the EMD dispatcher. Then, call taking, CA screening, and t-CPR are performed by trained firefighters. Calls are managed by, first, detecting unconscious victims. Then, after “rapid activation” of a BLS team, the HoB algorithm is performed to detect a potential CA; next, the dispatcher starts t-CPR according to a specific instruction list (Supplemental material).

Evolution of the DA-CPR program

In 2012, inspired by the AHA guidelines, a DA-CPR quality program was set up to introduce tutoring for the youngest operators by their more expert elders.[13] The tutors encouraged over-triage and a more systematic use of the HoB. When a CA was not detected, the tutor and operator listened again to the corresponding telephone call, to ensure positive assimilation. When dispatchers successfully detected a complex CA, a reward was given in the same way that any firefighter was rewarded after an outstanding intervention. Regular performance measurements were carried out, and the results were communicated to dispatchers to reinforce motivation.

Study design and population

A repeated cross-sectional design was planned for this study. We studied tapes of recorded telephone calls from four periods: 2012 (15−31 November), 2015 (26 January to 09 February), 2017 (1−15 October), and 2018 (1−30 November). In our servers, tape search is manual, particularly long and complex. The analysis periods were therefore chosen according to the availability of the technical teams, to the absolute exclusion of any other consideration. The 2018 period was chosen longer than the other periods because we wanted more precision in the measurement of delays and in the exhaustiveness of the reasons of wasting time (second endpoints). It has not been possible to increase the size of older periods (tape storage unavailable).

From the Sudden Cardiac Deaths in Greater Paris registry, we have included all OHCAs cared for by a BLS team during those periods. Two emergency physicians (C.D and O.T.) retrospectively listened to eligible telephone calls, and in case of disagreement, two others physicians evaluated the call (D.J and F.B.). We excluded calls, when the caller had detected the CA, when the caller was not located in close proximity to the patient, when the archived tape was corrupted, or when the call was a third-party call, according to the AHA definition of recognizable calls.[15]

Data collection

In addition to the Utstein variables, we collected data on the CA detection status, t-CPR delivery, and the breathing assessment. The CA was validated when the dispatcher pronounced the words "Cardiac Arrest" or "Chest Compressions". T-CPR delivery was considered successful, when, in the recording, the caller said they were doing chest compressions. The breathing assessment was classified as follows: assessment not realized; assessment realized without HoB; or assessment realized with HoB. Time intervals were derived from the call tapes.[16]

The main endpoint was the OHCA detection rate and its trend over the six-year study. Secondary endpoints were the rates and evolution of OHCAs detected by the operator; whether detection was followed by t-CPR; whether a defibrillator was requested; and the different time intervals derived from the call. Finally, we analyzed the 2018 cohort to identify possible factors associated with the times required to detect OHCAs and start t-CPR.

Statistics

Categorical variables are expressed as the frequency and proportion, with 95% confidence intervals. Qualitative variables are expressed as the mean and standard deviation or the median and interquartile range. Comparisons of variables among the four periods were performed with the Fisher exact test or analysis of variance (ANOVA), as appropriate. After describing the main patient characteristics, two logistic regression models were created to assess the variables associated with OHCA detection and with initiating t-CPR. The variables were selected for the model, based on (i) their clinical relevance and previous knowledge from the literature (location, age, sex, traumatic) (ii) a minimization with the Akaike information criterion, and (iii) always retaining the period in the model. When applicable, the inclusion of clinically relevant variables took precedence. Potentially relevant interactions were assessed for inclusion in the model.

The 2018 cohort subgroup analysis aimed to determine the frequency and the reasons for wasting time at different points during the telephone conversation about an OHCA. We classified each event/practice according to its potential for improvement, as follows: imperative, possible, difficult, or impossible. Similarly, we categorized the time wasted according to the person or event responsible, in this case: the caller, the dispatcher, the logistics or the technology. The event frequency did not predict the amount of time lost. All analyses were performed with R software, version 3.3.3 for Windows. The significance level was 5%.

Regulatory and ethical considerations

The data collection and processing were carried out in strict compliance with French regulations (CNIL MR003). The study was approved by the Ethics Committee of the French Anesthesia Society (IRB 00010254 – 2018 – 003).

Results

Over the 6 years of the study period, the number of calls increased by 5% per year, i.e. 870,000 more calls were taken in 2018 than in 2015, with the same number of dispatchers.

OHCA detection and t-CPR rate

Of 790 patients that experienced OHCAs, 321 were potentially recognizable by the dispatcher and were included in the analysis. Flowchart is available in Fig. 1. Patient, caller, and dispatcher characteristics are shown in Table 1. We also analyzed features of dispatcher work and basic and advanced life support. Among all patients that experienced OHCAs, 64 (8.1%) had received bystander-CPR before the call or a CA was detected before the call (Fig. 1).

In 2012, dispatchers assessed breathing for 71% of patients, and this proportion increased to 97% in 2018 (Fig. 2). Dispatchers correctly identified 54% of recognizable OHCAs in 2012, 76% in 2015, 83% in 2017, and 93% in 2018. The AHA performance goal was 95% among the identified OHCAs, t-CPR performance increased from 51% to 84% during the 6 years of observations. The AHA t-CPR performance goal was 75%. During the study period, the rate of dispatchers searching for a defibrillator increased from 0 to 20% and the rate of ongoing CC at BLS arrival increased from 36% to 83% ($p = 0.01$). In contrast, the rate of CPR-bystander before call did not improve significantly (4%–17%, $p = 0.22$), nor did the survival rate. Callers reported breathing movements in the recordings for 76 (24%) patients. Among the 21 patients discharged alive from hospital, 11 were CPC 1 and 6 were CPC 2 (4 data missing).

After adjusting for confounders, OHCA detection was associated with breathing assessments, particularly when assessed with HoB (aOR: 13.1 95%CI: 4.8–39.5), during the 2018 period (aOR: 3.4, 95%

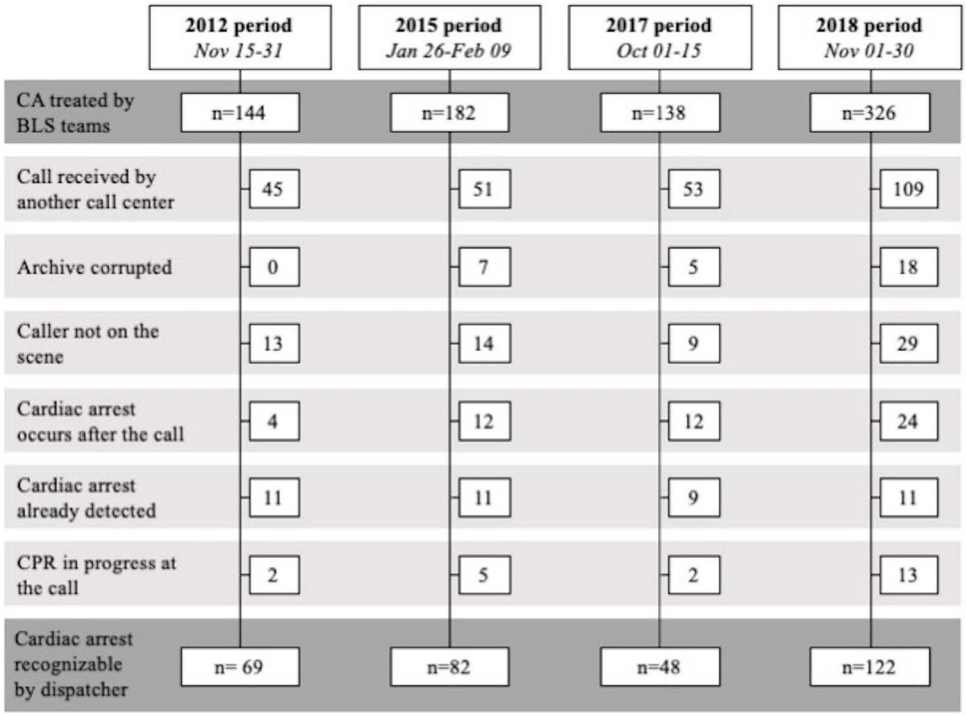

Fig. 1 – Flowchart of the selection of Out-of-Hospital Cardiac Arrest calls for analysis. CA cardiac arrest, CPR cardiopulmonary resuscitation, BLS basic life support.

Table 1 – Patients characteristics and outcome.

		Period 2012 n = 69	Period 2015 n = 82	Period 2017 n = 48	Period 2018 n = 122	p Value
Patient characteristics						
Male		45 (65)	49 (60)	30 (63)	71 (57)	0.74
Age, years		65 [51–79]	71 [58–84]	66 [55–81]	70 [55–81]	0.72
Out-of-Hospital Cardiac Arrest (OHCA) characteristics						
Location	Home	45 (65)	65 (79)	41 (85)	99 (81)	0.31
	Public/work place	18 (26)	17 (21)	7 (15)	23 (18)	
Traumatic cardiac arrest		4 (6)	6 (7)	2 (4)	7 (6)	0.95
Seizure at the call		2 (3)	3 (4)	3 (6)	6 (5)	0.86
Caller characteristics						
Caller-patient link	None	3 (4)	18 (22)	7 (15)	35 (29)	0.24
	Close relative/family	31 (45)	61 (74)	31 (63)	87 (71)	
Ability to perform CPR	None	26 (38)	61 (74)	34 (71)	101 (83)	0.22
	First-aid/healthcare worker	3 (4)	18 (22)	4 (8)	21 (17)	
Dispatcher work						
Breathing assessment	Not realized	20 (29)	14 (17)	7 (15)	4 (3)	<0.001
	Yes without HoB	23 (33)	17 (21)	1 (2)	20 (16)	
	Yes with HoB	21 (30)	51 (62)	41 (83)	99 (80)	
Number of Hand on Belly (HoB) tests	1		25 (49)	22 (54)	46 (46)	0.64
(on breathing assessment with Hob)	2	*N/A*	16 (31)	11 (27)	44 (44)	
	>2		10 (20)	8 (19)	9 (9)	
Breathing movements reported by caller or audible on the tape (%)		14 (20)	15 (18)	13 (27)	34 (28)	0.48
Recognizable OHCA correctly identified		37 (54)	62 (76)	40 (83)	113 (93)	<0.001
Correctly identified OHCA receiving t-CPR		19 (51)	52 (84)	33 (83)	95 (84)	<0.01
Total OHCA[a] cases correctly identified		50 (53)	78 (66)	52 (70)	142 (72)	0.01
Correctly identified OHCA with dispatcher asking for a defibrillator (%)		0	6 (10)	8 (20)	23 (20)	0.01
Basic and advanced life support						
CC ongoing at BLS arrival		25 (36)	51 (62)	35 (73)	101 (83)	0.01
Shock delivered by AED ≥1		15 (22)	15 (18.3)	14 (28)	32 (26)	<0.01
Survival until hospital admission		19 (28)	21 (26)	17 (35)	32 (26)	0.63
Discharge alive from hospital		5 (7)	3 (4)	4 (8)	9 (7)	0.12
Dispatcher characteristics						
Dipatcher age, years		30 [28–32]	32 [30–34]	33 [30–37]	30 [28–34]	0.05
Seniority at the EMD, years		4.0 [3.5–4]	1.4 [0.3–3.2]	3.0 [3–3]	2.7 [1.4–3.8]	<0.001

Data are in number (%) or in median [25th–75th].
HoB: Hand of Belly method for OHCA detection; CC: chest compressions; EMD: emergency medical dispatch.
[a] Included recognizable OHCA, archive corrupted, caller not on scene, cardiac arrest already detected by caller and CPR ongoing before the call, but not 3rd party call (no specific details for measures are available on AHA recommendations).

CI: 1.1–10.8), and when the OHCA occurred in a public place (aOR: 0.14, 95%CI: 0.05–0.4) (Table 2), compared to an OHCA at home. When only the detected OHCAs were considered, the t-CPR was associated with younger patients and with the HoB breathing assessment. Neither the age nor the seniority of dispatchers was associated with the success of OHCA detection or t-CPR. The sensitivity of HoB for CA detection was measured among patients at 96.2%.

Delay measurement

In 2015, callers could directly call the EMD within 25 s (95%CI: 15–35). In 2018, callers first contacted the PSAP within 14 s (95%CI: 12–20), then the EMD within 48 s (95%CI: 40–68). The AHA minimum acceptable standard was 60 s (Fig. 3). No call was ended before processing by a dispatcher, and the longest times to picking up the call were 68, 36, and 24 s, in 2015, 2017, and 2018, respectively.

The median time interval between a "1-1-2 call" and sending a BLS remained broadly unchanged between 2012 and 2018. The time interval to OHCA recognition increased by about 40 s between 2012 and 2018, from 168 s (95%CI: 128–206) to 210 s (95%CI: 164–285). Moreover, the time interval between the "1-1-2 call" and the beginning of t-CPR increased by 109 s during the same time period (from 230 s, 95%CI: 208–330 to 339 s, 95%CI: 256–454). For the two latter time intervals, the AHA minimum acceptable standard was 150 s, which was exceeded most of the time.

2019 cohort analysis

The 2018 cohort included 122 calls. Time was wasted during 59% of the calls at the PSAP and during 95% of the calls at the EMD (Table 3). There were 36 reasons for wasting time, and of these, 16 seemed impossible to change, 8 seemed difficult to correct, 5 seemed possible to correct, and 7 were subject to mandatory prompt correction.

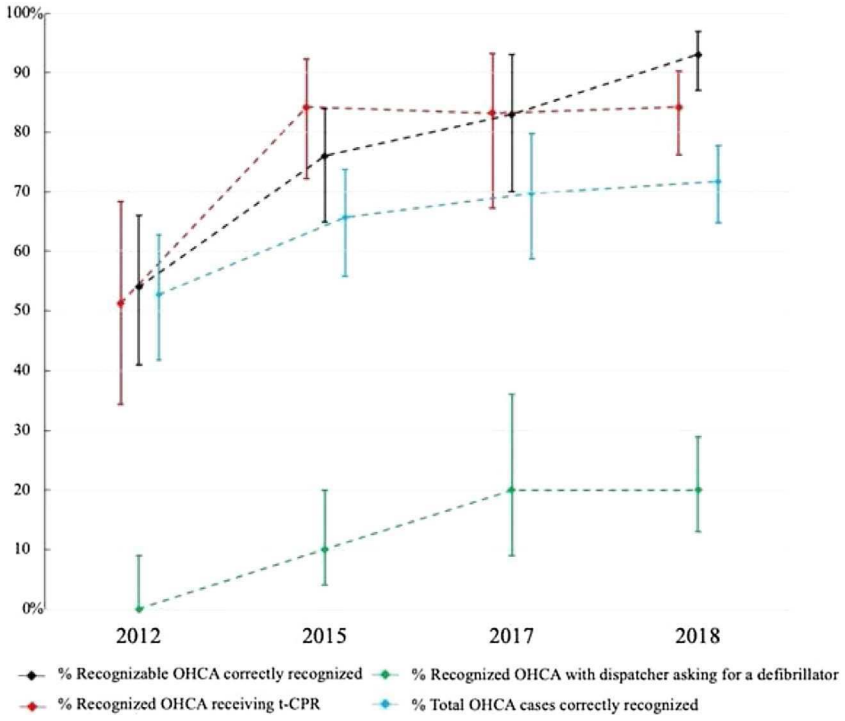

Fig. 2 – Out-of-Hospital Cardiac Arrest detection and telephone-assisted cardiopulmonary resuscitation rates. OHCA: Out-of-Hospital Cardiac Arrest; t-CPR: telephone cardiopulmonary resuscitation.

Table 2 – Multivariate analysis for OHCA detection and t-CPR on complete cases (respectively n = 312 and n = 239 observations).

	Multivariate analysis for OHCA detection		Multivariate analysis for t-CPR on recognized OHCA	
	OR [95% CI]	p	OR [95% CI]	p
2012 period	1		1	
2015 period	1.6 [0.6–4.5]	0.38	4.9 [1.9–17.0]	0.002
2017 period	1.2 [0.3–5.1]	0.76	5.0 [1.5-18.5]	0.01
2018 period	3.4 [1.1–10.8]	0.03	5.2 [2.0–13.6]	<0.001
OHCA at home	1		1	
OHCA on street/workplace	0.14 [0.05–0.4]	<0.001	2.1 [0.6–9.5]	0.28
Breathing assessment without HoB	1		1	
No breathing assessment	0.14 [0.05–0.4]	0.001	0.25 [0.02–2.20]	0.24
Breathing assessment with HoB	13.1 [4.8–39.5]	<0.001	2.9 [1.2–7.0]	0.02
Patient age, per 10 years older	0.95 [0.8–1.2]	0.65	0.01 [0.01–0.01]	<0.001
Gender (male:ref)	1.22 [0.5–3.0]	0.66	0.6 [0.3–1.3]	0.19
Dispatcher age, per 5 years older			0.72 [0.5–1.1]	0.12
Medical cardiac arrest (trauma:ref)			0.23 [0.05–1.06]	0.05

OHCA: Out of Hospital Cardiac Arrest; OR: odd-ratio; 95%CI: 95% confident interval, HoB: Hand of Belly method for OHCA detection.

Discussion

Main results and DA-CPR program results

The main finding of this study was that the OHCA detection rate significantly and constantly increased, from 2012 (54%) to 2018 (93%). At the same time, the percentage of recognized OHCAs that received t-CPR increased from 51% to 83%. From 2017, our results almost achieved the goals recommended by the AHA; i.e., rates of 95% and 75%, respectively.[14] Our rates were close to the highest reported in the literature,[17–19] and they were associated with a significant increase in the rate of patients that received ongoing CC at BLS arrival; indeed, our rates exceeded the French and Swedish national average rates (53% and 68.2%, respectively).[20,21] We demonstrated that the application of a DA-CPR program, with its three components – algorithm, operator training, and performance measurements – could effectively improve the rates of OHCA detection and ongoing CPR at BLS arrival. On the other hand, there was no increase in the shockable rhythm rate or in patient survival, as might have been expected. This lack of downstream effects could be related to excessively long delays before starting the CCs, stagnation

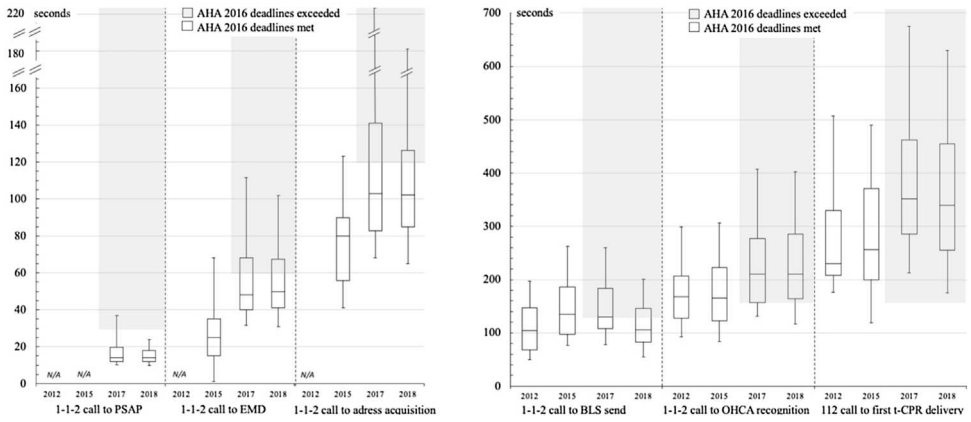

Fig. 3 – Time intervals (s) for the six steps of dispatch-assisted cardio-pulmonary resuscitation, shown for each year included in the study. PSAP: public safety answering point; EMD: emergency medical dispatch; OHCA: Out-of-Hospital Cardiac Arrest; BLS: basic life support team; t-CPR: telephone-assisted cardiopulmonary resuscitation; AHA: American Heart Association.

in CC quality, and/or difficulty in monitoring the depth of compressions remotely.[22–25] Despite the absence of AHA guidelines for locating a defibrillator, the rate of searching for a defibrillator increased until 2017, and then it remained constant. The search for defibrillators was then assigned to chief dispatchers, who were trained in using the "Staying Alive" mobile-responder application and defibrillator mapping.[26]

Hand on Belly algorithm

The main factors associated with successful OHCA detection were the occurrence of a CA outside a public place and the operator recognizing the ventilation status, particularly when the status was ascertained with the HoB. In 2012, the Paris Fire Brigade dispatch center was using the AHA question "is the patient breathing normally?", without systematically using the HoB technique.[2,13] The problem with this question was that the definition of "normal" was subjective. Similarly, the answer to this question was based on complex linguistic characteristics that could mislead the dispatcher, particularly when the patient displayed agonal breathing.[27] Currently, the AHA question is commonly used to draw the caller's attention to the ventilation status; then, the question is quickly followed by the HoB method, which has become the reference in our system. The HoB method quantifies the respiratory rate; it is based on the fact that the termination of gasps begins from the abdomen. The use of HoB was associated with a higher t-CPR rate, because it required the rescuer to adopt a physical position quite similar to that of a CC provider.[28]

Public places were adversely associated with the detection of OHCAs. In fact, a high incidence of gasping and a large number of bystanders at the time of the collapse are well-known risk factors for non-detection, and they present a major challenge to dispatchers.[2,4,6,29,30]

Dispatcher training

Initial training

All the dispatchers included in the study had at least 3 years of BLS experience; this was an important prerequisite for comprehending clinical situations over the telephone.[29] In addition to their seniority, which was not associated with CA detection, their initial training program was crucial to improving detection. The initial dispatcher training consisted of approximately 150 h of training, including about 10 h specifically focused on OHCA detection and CC guidance.

Continuous training

The rate of calls to the PSAP and to the EMD increased significantly during the study period, but the number of dispatchers remained constant, at 140. These dispatchers handled about 48,000 calls over each 15-day period, and they had the opportunity of detecting about 70 CAs, which comprised about 0.15% of all calls. Therefore, OHCAs were rather rare events for each operator. However, the HoB was performed for all unconscious patients, which were more numerous than patients with CAs. The number of CAs processed by an operator was associated, based on the literature, with more frequent CA detection by that operator; continuous training was also crucial in maintaining a high level of detection.[6,7,31] In our experience, motivation was reinforced by dispatcher awards and postings on social networks of encounters with survivors. In addition, the heads of the call centers, doctors, and dispatchers contributed to animating the dynamics around CAs at the dispatching center. For example, some innovative projects included implementing "Staying Alive" mobile dispatch application, for lay responders, and the Corti® artificial intelligence application, for dispatchers.[26,32,33] The HoB method was used by dispatchers that were basic firefighters trained in CA detection. Accordingly, we believe that the HoB method could potentially be deployed in other dispatch centers.

Improved time intervals

The time intervals from the 1-1-2 call to the PSAP, to the EMD, to acquiring the address, and to sending the BLS team were most often within the limits recommended by the AHA. In 2016, the transition from a one- to two-level call center was necessary, due to the addition of police dispatches to the Paris Fire Brigade dispatch center. This new organization and the ever-increasing number of calls have been associated with an increase in the time to contact the EMD, but not in the time required to send a BLS team (105 s in 2012 vs. 106 s in 2018). The time added by this two-level system was an investment in the successful

Table 3 – Frequency of reasons for wasting time at different time points during the telephone conversation for reporting a cardiac arrest in the 2018 cohort.

	n	%	*	†
Reasons for time wasted at the Public Safety Answering Point	73	(59)		
Dispatcher asked inappropriate questions	4	(3)		++
Caller stress	13	(11)		-
Caller did not answer questions or provided unnecessary details	18	(15)		+/-
Caller repeatedly asked to send help	20	(16)		+/-
Caller spontaneously gave his name and address	45	(37)		+/-
Time wasted between contacting the PSAP and EMD				+
Reasons for time wasted at the Emergency Medical Dispatch,	117	(95)		
Total time wasted for address acquisition	65	(53)		
The address did not exist in the computer database	5	(4)		++
Caller did not know the building access codes	5	(4)		+/-
Dispatcher misunderstood the spelling of a street name	6	(5)		+/-
Accent hindered comprehension	7	(6)		-
Caller did not know the address of his/her location	11	(9)		++
Dispatcher interrupted taking the address with questions	13	(11)		+
Caller did not answer questions or provided unnecessary details	37	(30)		+/-
Reasons for time wasted in the diagnosis of unconsciousness	57	(46)		
Difficulty moving a heavy patient	5	(4)		-
Unreliable caller responses	9	(7)		-
Dispatcher delayed asking about unconsciousness	13	(11)		++
Dispatcher interrupted the consciousness check with other questions	17	(14)		++
Caller had to move to check on the patient	19	(15)		-
Caller stress	21	(18)		-
Reasons for time wasted in determining no/abnormal ventilation	49	(40)		
Dispatcher stress	2	(2)		+
Crowd interfered with the evaluation	7	(6)		-
More than two Hand on Belly evaluations	9	(7)		++
Lost communication: the dispatcher called the caller back	9	(7)		-
Difficulty moving a heavy patient	15	(12)		-
Patient experienced cardiac arrest during the call‡	20	(16)		-
Unreliable caller responses	21	(17)		-
Reasons for time wasted in starting t-CPR	99	(80)		
Delay due to the installation of a defibrillator	1	(1)		+
Dispatcher feeling futility	10	(8)		+/-
Crowd interfering with caller gestures	12	(10)		-
Caller feeling futility	13	(11)		-
Caller went to get a neighbor for help	15	(12)		-
Dispatcher's explanations too long for performing the CPR	18	(15)		++
Caller stress	22	(18)		-
Dispatcher asked caller for patient medical history	30	(24)		+
Dispatcher asked caller to check for no flow, cold, and/or stiffness	42	(34)		+/-
Caller difficulty moving a heavy patient	47	(38)		-

*Color coding indicates wasted time due to caller (blue), dispatcher (green), or logistics and technology (yellow).
†Improvements in practices were rated as imperative (++), possible (+), difficult (+/−), or impossible (−). Frequency did not predict the amount of time lost.
‡or gasping at intervals <7 s at the beginning of the call.

detection of CAs in more critical patients. With this system, the order of answering calls moved from chronological priority to medical priority. Conversely, the time interval between OHCA screening and the start of t-CPR increased over the years. Screening for more complex OHCAs and OHCAs that occurred at the end of the call increased the rate of OHCA detection, but the time intervals also increased.[34] Repeating the HoB more than twice could also increase delays.

To overcome the delays and reduce no-flow, all actions are legitimate when they limit the time to sending the BLS and starting t-CPR. In the 2018 cohort, there were 15 caller-related reasons for time wasted. Resolving these issues might be expensive and time-consuming; it may require a program for training the population in life-saving actions. However, this approach could reduce the time to applying a defibrillator. To resolve dispatcher-related delays, it may be possible to provide continuous training in communication techniques, like reformulating instructions, requesting feedback, practicing slower speaking rates, improving diction, adapting the language, using transition sentences . . . etc. In addition, dispatchers should be reminded to respect the protocol (i.e., no more than two HoBs; complete one task before starting another). Moreover, the checklist for t-CPR has improved from 7 + 6 steps in 2012 to 5 + 8, in 2019 (Supplemental material).[35,36]

In the present study, all calls were authenticated cardiac arrest calls: we did not measure the false positive rate for HoBs, because of the technical and logistical impossibility of manual screening among our 14,500 daily calls (1,087,000 calls over the 75 study days). In any case, we assumed over-triage conditions, which appeared to have little negative effect on patients with a beating heart.[37] One technology-related reason for time wasting was that the PSAP and EMD used different call-taking software, which required the caller to repeat the information. One third of callers spontaneously gave their address to the PSAP, when it was not useful. Neither level had a smartphone/ landline phone geolocation system, like the *Advanced Mobile Location* application. A new national software interface, with more reactive mapping, is planned for implementation in 2021.[38] Computer-assisted screening is also a very promising method for the future.[32] This method aims to offer quality screening that is independent from fatigue, reduced concentration, or inappropriate questions from the dispatcher.

Limitations

Among the 10 OHCAs/day that occurred, only half was recognizable, according to the definition of the AHA. This rate was well below the 80% previously reported by Lewis et al.[2,15] This rate might be explained by calls from a third party, due to the several emergency numbers available in France.

An optimal OHCA dispatch method should achieve a high detection rate, a high t-CPR rate, and a rapid execution rate. Our study confirmed the effectiveness of the HoB method; this system achieved a CA detection rate and t-CPR rate close to the highest levels required by the AHA. However, there is a potential cost in time before CPR initiation, based on the accuracy of recognition and communication between the phone and caller. The optimal HoB method (i.e., not repeated more than twice) might be equivalent or more effective than the alternative method of: *NO (consciousness), NO (breathing), and GO (chest compressions)*.[39]

We do not believe that a different number of patients between each study period could bias the size of the effect, i.e. in our case the sensitivity of the screening process even if it affects variance. However, we observe a difference between the periods/strategies, meaning that there is a sufficient number of patients for each period for us to detect it. Although we did not identify any other confounders that might have affected the results during the study period, we could not rule out the possibility that other confounding factors might have existed.

Conclusion

The HoB effectively facilitated OHCA detection in our system, which has achieved very high performance levels.

Institution were the work was performed

Paris Fire Brigade.

Funding

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Disclosures

None.

Conflicts of interest

None.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.resuscitation.2019.10.038.

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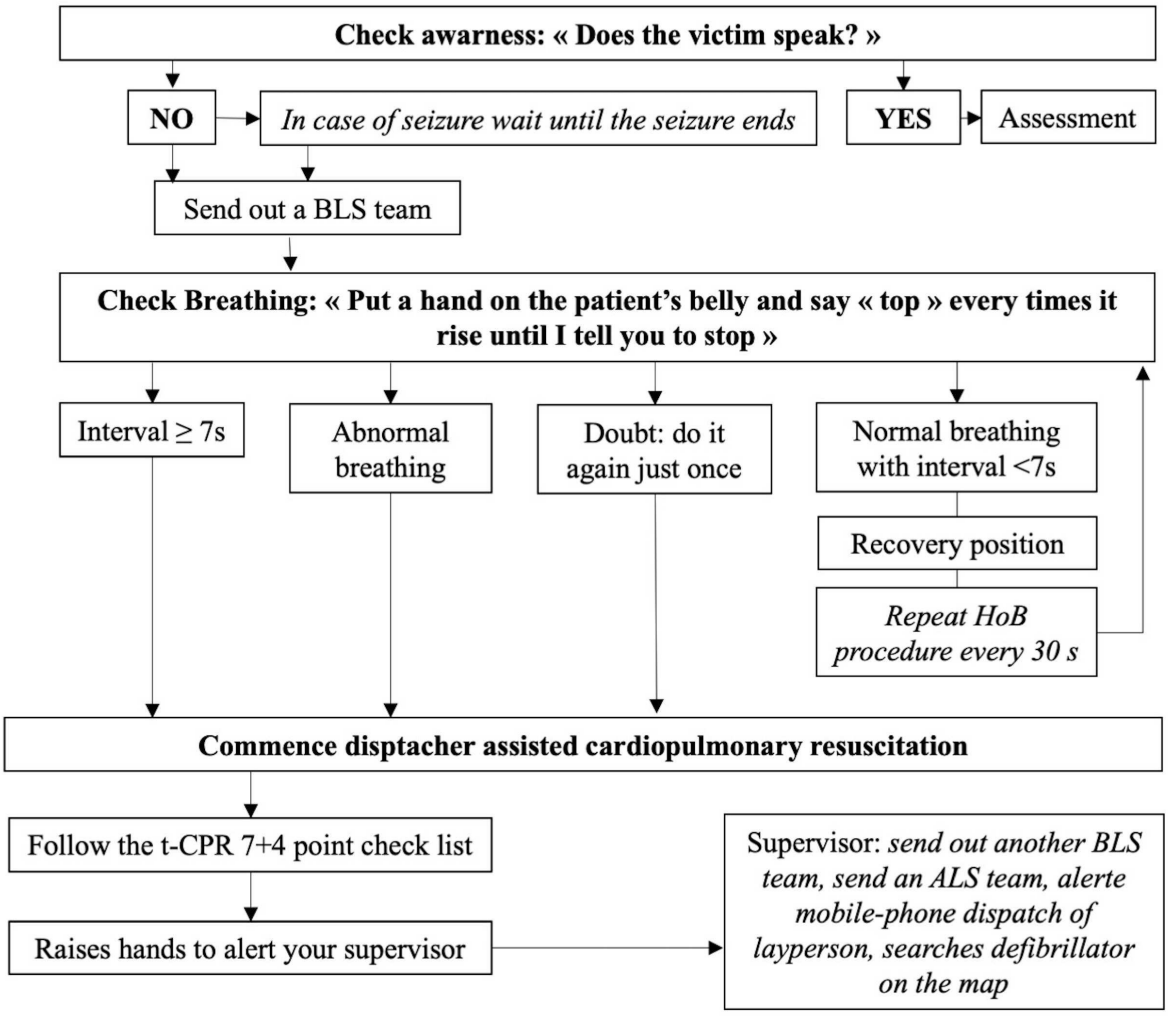
Supplemental material of Improving emergency call detection of Out-of-Hospital Cardiac Arrests in the Greater Paris area: Efficiency of a global system with a new method of detection

Additional Figure 1: Hand on Belly algorithm



Two BLS teams are sent since we read "Warren SA, Prince DK, Huszti E, Rea TD, Fitzpatrick AL, Andrusiek DL, et al. Volume versus outcome: More emergency medical services personnel on-scene and increased survival after out-of-hospital cardiac arrest. Resuscitation. 2015;94:40-8."

Additional Table 1: The 2012 list of 7+6 instructions and the 2019 list of 5+8 instructions for guiding telephone-assisted Cardio-Pulmonary Resuscitation (t-CPR)

2012 list of 7+6 instructions for guiding t-CPR

Processing Chest Compressions

1. The ambulance is on its way, I'll help you do chests compressions
2. Put your phone on speaker, and listen to me carefully
3. Lie the victim on the ground, with his back flat; extend the victim's arm at 90° to the side of the body
4. Kneel next to the victim, straddling his arm
5. Place your hands on top of each other, in the middle of the line that connects the 2 nipples, between the 2 breasts
6. Keep your arms straight, press as hard as you can every time I say « top ». Did you understand?
7. **« TOP TOP TOP ..... »** Make sure your buttocks are off your heels

Improving Chest Compressions

8. Now you say « TOP» every time you press down on the chest
9. Never stop, even when I'm talking to you, until help arrives and you are replaced. I'll stay on the phone with you.
10. Do you know if there is a defibrillator nearby, can you ask someone to get it?
11. That's very good, keep doing what you're doing; “help is coming soon”
12. Improving the technique:

    Release completely between compressions

    Keep up the pressing

    Press only with the heel of the hand

Keep your arms straight

13. Can someone replace you to make sure the compressions remain effective?

2019 list of 5+8 instructions for guiding telephone-assisted Cardio-Pulmonary Resuscitation

Processing Chest Compressions

1. Rescue is on the way, I'll help you to perform the fastest CPR massage possible
2. Is there a defibrillator nearby? Can you ask someone to go and get it?
3. Put your phone on speaker, and listen to me carefully
4. Lie the victim on the ground, with his back as flat as possible
5. Kneel next to the chest and place your hands, one on top of the other, between the two breasts. Press hard every time I say “top”; **“TOP TOP TOP TOP…”**

Improving Chest Compressions

6. Keep your arms straight, press harder “TOP TOP TOP TOP…”
7. Raise your buttocks off your heels
8. Now you say “TOP” each time you press
9. Keep up the pace, you can stop saying “TOP”. Keep breathing
10. Never stop pressing, even when I'm talking to you, until help arrives and someone replaces you. I'll stay on the line with you. Press harder
11. That's very good, keep doing what you're doing, help is coming soon. Press harder
12. Improving the technique:

    Release completely between compressions

    Keep pressing hard

    Press only with the heel of the hand

Keep your arms straight

13. Can someone replace you to make sure the compressions remain effective?

7.2. Mobile Smartphone Technology Is Associated With Out-Of-Hospital Cardiac Arrest Survival Improvement: The First Year “Greater Paris Fire Brigade” Experience

Mobile Smartphone Technology Is Associated With Out-of-hospital Cardiac Arrest Survival Improvement: The First Year "Greater Paris Fire Brigade" Experience

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ABSTRACT

Background: Out-of-hospital cardiac arrest (OHCA) remains associated with very high mortality. Accelerating the initiation of efficient cardiopulmonary resuscitation (CPR) is widely perceived as key to improving outcomes. The main goal was to determine whether identification and activation of nearby first responders through a smartphone application named Staying Alive (SA) can improve survival following OHCA in a large urban area (Paris).

Methods: We conducted a nonrandomized cohort study of all adults with OHCA managed by the Greater Paris Fire Brigade during 2018, irrespective of mobile application usage. We compared survival data in cases where SA did or did not lead to the activation of nearby first responders. During dispatch, calls for OHCA were managed with or without SA. The intervention group included all cases where nearby first responders were successfully identified by SA and actively contributed to CPR. The control group included all other cases. We compared survival at hospital discharge between the intervention and control groups. We analyzed patient data, CPR metrics, and first responders' characteristics.

Results: Approximately 4,107 OHCA cases were recorded in 2018. Among those, 320 patients were in the control group, whereas 46 patients, in the intervention group, received first responder–initiated CPR. After adjustment for confounders, survival at hospital discharge was significantly improved for patients in the intervention group (35% vs. 16%, adjusted odds ratio = 5.9, 95% confidence interval = 2.1 to 16.5, $p < 0.001$). All CPR metrics were improved in the intervention group.

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Paul Dardel is the Chairman of Staying Alive Responder Endowment Fund. He is remunerated by AEDMAP, the start-up behind the creation of Staying Alive Responder Endowment Fund. The other authors have no potential conflicts to disclose.
Author contributions: CD, DJ, ST, FR, and AM conceived the study and designed the trial; CD, BF, LP, ER, XD, OS, FB, FL, XL, OM, EG, and EP supervised data collection; CD, DJ, AM, and FR provided statistical advice on study design and analyzed the data; AM, CD, DJ, RK, and BP drafted the manuscript; and all the authors contributed substantially to its revision.
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Conclusions: We report that mobile smartphone technology was associated with OHCA survival through accelerated initiation of efficient CPR by first responders in a large urban area.

Out-of-hospital cardiac arrest (OHCA) is a leading cause of death. While one episode of OHCA occurs every 6 minutes in France, fewer than one in six cardiopulmonary resuscitation (CPR) attempts is successful.[1] In Greater Paris, an average 10 OHCA events occur every day, with a survival rate approximating 7.5%.[2] Overall, outcomes following OHCA thus remain very poor despite information campaigns, structured training programs, and improved public access to automated external defibrillators (AEDs).[3,4] Interventions designed to improve the second link of the chain of survival (early initiation of effective CPR) are widely identified as most likely to save lives.[5,6] Unfortunately, since bystanders only rarely initiate CPR, median times to Basic Cardiac Life Support (BLS) remain high in France (18 minutes),[1,7] including in large urban areas such as Greater Paris (9 minutes).[8]

Beyond adequate identification of situations requiring CPR, optimized dispatch of first responders is key to initiate BLS and accelerate access to AED. Widespread availability of mobile smartphone technology (MST) not only allows alerting nearby first responders, it also facilitates localization of nearby AEDs. Once alerted through notifications, nearby first responders may rush to the scene to promptly initiate BLS before a full medical team arrives to provide Advanced Cardiac Life Support (ACLS). MST strategies have been successfully implemented in numerous countries, leading to increased first responder–initiated CPR attempts. While survival benefits remain to be demonstrated,[8–16] MST strategies are currently part of international guidelines.[17–19]

In France, the mobile application "Staying Alive" (SA) allows nearby first responders, commonly referred to as "Bons Samaritains" (BS), to be located and alerted. SA is available on all smartphone platforms and uses geolocalization services to flag nearby AEDs. It was first integrated to the Paris Fire Brigade Greater Paris Area CPR protocols in 2017.[16] We hereby summarize how the introduction of SA improved health care delivery and OHCA survival outcomes within 1 year in Greater Paris area (July 2017 to 2018).

METHODS

SA Mobile Smartphone Application

Staying Alive is a free mobile smartphone application, available in 18 languages (French, English, Spanish, Chinese . . .), that is compatible with all operating systems. Back in 2011, SA's original version was devoted to AED mapping and developed by "AEDMAP" startup. The application is free for dispatch centers, AEDMAP is funded thanks to public and private sponsorship. Since then, SA has been updated to allow CPR-trained volunteers (BS) to register after providing a certificate of training. When necessary, BS can be easily located and alerted if notifications are turned on. Once alerted, they may accept or decline to rush to the scene of the cardiac arrest. The dispatch center may also direct activated BS toward the nearest AED through SA. Over time, SA has contributed to create a community of BS has received support from several institutions and sponsors.

To rapidly increase their number, we published in the local press and on social networks joint interviews of the first BS who had intervened and of the patients who had survived. We also communicated within the Paris Fire Brigade and its partners (red cross, civil protection), who constitute an important pool of BS and who added many AEDs to our database via the application.

Global Resuscitation Strategy in Greater Paris

The Greater Paris area is 800 km^2 wide; it hosts about 7 million people. The Paris Fire Brigade dispatch center receives approximately 1.2 million telephone calls each year. Each day, it responds to an average of 10 OHCA alerts using a dispatch-assisted CPR protocol set in 2012. The emergency medical system (EMS) is a two-tiered response system.[2,20] The first tier is activated every time loss of consciousness is suspected and a BLS team is immediately sent out. The second tier is activated when OHCA is confirmed by the dispatcher, using the previously published "Hand on Belly."[20] In this technique, the dispatcher asks the bystander to put his hand on the victim's belly to estimate the ventilatory frequency. If there are more than 7 seconds between two movements, the dispatcher makes the diagnosis of cardiac arrest. Bystanders receive telephone instructions to initiate chest compressions (t-CPR) or use an AED until the BLS team or EMS providers arrive on the scene.

SA Activation

Staying Alive was deployed in the dispatch center in 2017. Whenever OHCA is confirmed, the chief dispatcher may decide to activate SA in addition to standard second tier EMS responses. SA activation maps AED available around the scene; it also identifies and alerts BS within a 500-meter radius (Figure 1; Data Supplement S1, Video S1, available as supporting information in the online version of this paper, which is available at http://onlinelibrary.wiley.com/doi/10.1111/acem.13987/full). Per agreement, given that MST strategies were still considered experimental in France, we decided that only trained volunteers could register as BS. Chief dispatcher activates SA for all cardiac arrests, 1) in public places (approximately 20% of OHCA in the greater Paris), 2) in the absence of environmental danger for registered BS, and 3) based on the availability and assessment of the chief dispatcher of which this is one of many functions. By definition, SA was activated only on OHCAs detected by our dispatch center, which is all the more difficult in public places (younger patients, frequent gasps; about 50% in our center).[21]

When necessary, all available registered BS near an OHCA scene receive a "push" notification with a sound alarm, even if the phone is locked. SA does not need to run in the background. Upon acknowledgment of the notification, available BS are directed toward the scene of OHCA and receive a map of AEDs in the area. One or more BS may respond to an alert and rush to the scene. Registered BS can control their availability and activation status using the SA application. The chief dispatcher can track status changes ("available," "dispatched," "on the way") remotely. The chief dispatcher can also contact a BS directly. We assigned the activation and management of SA to the chief dispatcher, since our top priority was not to interfere with what was working, i.e., the guidance of the chest compressions by the first dispatcher.[20,21] This is a difficult telephone procedure that requires focus and is not compatible with other tasks.

Study Design

The Paris Fire Brigade conducted a single-center observational cohort study on SA implementation and efficacy between July 2017 and July 2018. All OHCA events in the Greater Paris Area during that period were analyzed. The following data were collected: 1) return of spontaneous circulation (ROSC; prospective Utstein-style[2] paper database on the scene by Paris Fire Brigade EMS and BLS teams); 2) hospital outcomes (retrospectively confirmed by the Paris Sudden Death Expertise Center in patients hospital records); 3) AED use as well as BS identification and activation through the SA database; and 4) BS characteristics (demographics, first aid level), feedback, and actions on the scene through a telephone interview within 1 month following the alert.

We defined two groups of patients. The intervention group included all OHCA patients for which one or more BS was identified, rushed to the scene, and started BLS as defined by 1) the initiation or continuation of lifesaving maneuvers such as chest compressions; 2) the localization, retrieval, application, and usage of an AED; 3) the combination of 1) and 2). The control group included: 1) cases in which no BS was available within the 500-meter radius, 2) no BS responded to the request, 3) at least one BS responded but none eventually reached the scene, and 4) at least BS reached the scene but none performed any resuscitation effort. Since many BS may have been involved for one OHCA, some results may include different numbers of either BS or patients.

Endpoints

Comparing cases where SA was activated to those where SA was not activated, we analyzed the rate of ROSC upon hospital admission. Comparing patients in the intervention and control groups, we analyzed survival outcomes upon hospital discharge. We also analyzed the impact of BS response on survival outcomes.

Data Analysis

Initial Data Reduction. Continuous variables are described with medians and IQR (25th–75th percentile). Categorical parameters are summarized with numerical values and percentages. Differences between proportions were analyzed with the Fisher's exact test. We used the Mann-Whitney U-test to compare differences between unpaired groups. All statistical tests were two-sided and a $p < 0.05$ considered significant.

Propensity Score Model. We designed a propensity score analysis using complete cases, matching with a greedy algorithm. The propensity score for the SA application success was computed using the Super Learner (SL). The SL is a combination of machine learning methods that was previously

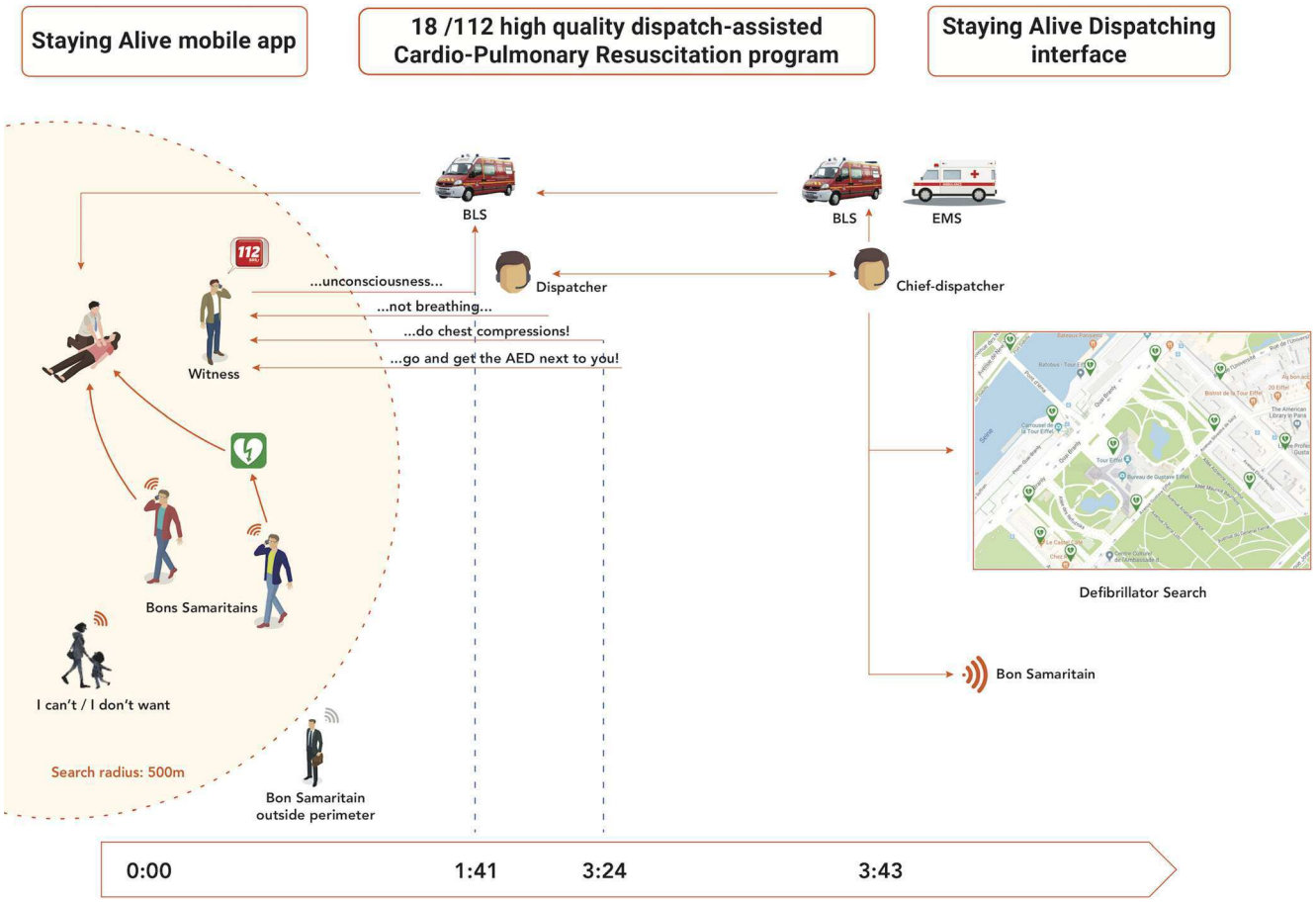

Figure 1. SA operating system and dispatch by the Greater Paris Fire Brigade. (1) The bystander calls for help, (2) the dispatcher detects unconsciousness and immediate sends team (BLS), (3) the dispatcher detects no/abnormal respiration, (4) the dispatcher guides the bystander to perform chest compressions, and (5) the dispatcher alerts chief dispatcher. The chief dispatcher (6) alerts BS and searches automatic public defibrillator and (7) sends second BLS and emergency medical service teams. (8) BS accept (or not) the alert, rush to perform chest compressions, and/or retrieve a defibrillator. (9) The first dispatcher can also guide the second bystander to a defibrillator if chief dispatcher indicates there is one nearly. The time scale indicated is the based on the median time recorded at the fire brigade dispatch center in 2017. BS = Bons Samaritains; BLS = Basic Life Support; SA = Staying Alive.

demonstrated beneficial in this context.[22–24] It improves the robustness of propensity score matching estimators to propensity score model misspecification.[25] All available variables describing preexisting conditions were included in the propensity score model. These variables were derived from the Utstein-style guidelines for uniform reporting of cardiac arrest.

Matching Parameters. Matching on the propensity score was performed using a one-to-many variable ratio matching with a nearest neighbor-matching algorithm. We set a prespecified caliper equal to 0.2 times the standard deviation of the logit of the propensity score. Replacement of controls was used to limit number of unmatched treated. The R software package "Matching" was used to process matching. To assess balance between matched groups, standardized differences were calculated and a difference between (−0.1 and +0.1) indicates balance between groups.

Outcome Model. A logistic regression model was fitted for the survival analysis between the intervention and control groups. To account for controls matched more than once and the resulting correlation, we used a generalized estimating equations method. If necessary, the final model was adjusted on the residual unbalanced variables between the matched populations. Adjusted odds ratios (ORs) and 95% confidence intervals (CIs) were reported with robust variance estimates.

Causal Estimands Effect. The causal estimands effect in this study is the average treatment effect on the treated group (ATT). Whereas ATT and average treatment effect (ATE) are equivalent in a randomized clinical trial, ATT and ATE are not necessarily the same in an observational study. The effect measured in this study, which focuses on ATT, quantifies the answer to the following question: what would be the

patient's outcome in the intervention group if they had not been exposed to SA? We used the R software version 3.3.3 for Windows for all analyses.

Ethics

This study was approved by the Ethics Committee of the French Anesthesia Society (IRB 00010254-2018-003). French regulations were respected (CNIL, MR003).

RESULTS

SA Application

From July 2017 to July 2018, the number of BS who registered in SA rose from 5,582 to 23,312 in France, 3,241 of which were located in the Greater Paris area. By July 2018, there were 6,821 AEDs tagged by SA in Greater Paris.

Patients

The Sudden Death Expertise Center recorded 4,107 OHCA events within the year of data collection (Figure 2). Characteristics of the study cohort are detailed in Data Supplement S1, Table S1, separating cases where SA was activated or not. SA was appropriately activated 366 times (9.8%). In the intervention group (n = 46), lifesaving maneuvers such as chest compressions were initiated without AED use in 24 cases. An AED was used without attempting lifesaving maneuvers in 18 cases (CPR already ongoing by bystander). Finally, both lifesaving maneuvers and usage of an AED were achieved in four cases. In the control group (n = 320), nearby BS failed to respond to notifications in 97 cases. Although the remaining 226 BS did respond to notifications, they either failed to locate the site of OHCA or did not start BLS once on the site of OHCA. For all the patients, it was the first cardiac arrest.

BS

Staying Alive was activated 366 times following an OHCA event: the search of BS within a 500-meter radius succeeded in 269 cases (73%). A total of 762 push notifications were sent out, because one, two, three, four, or more BS were identified by the application in 58, 32, 24, and 41 cases, respectively. Approximately 226 (30%) of the 762 push notifications were

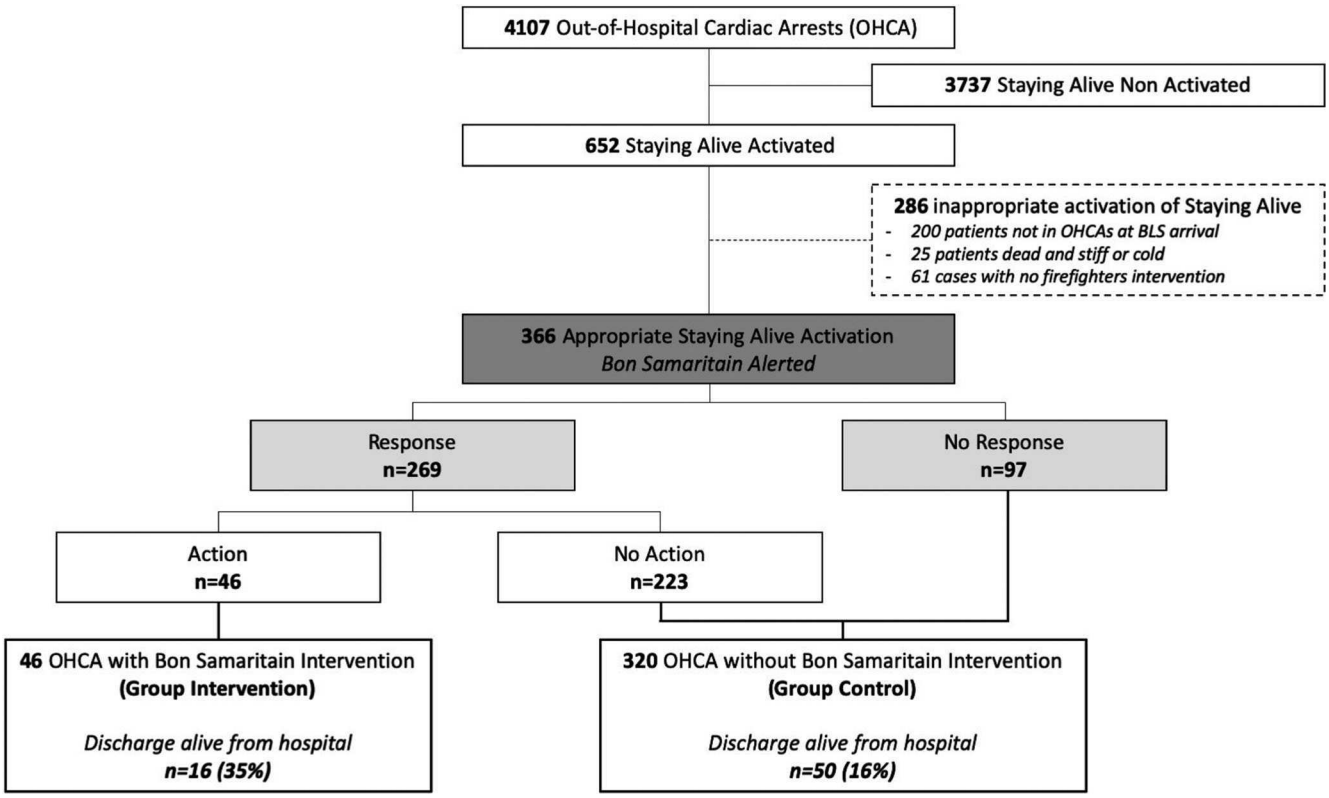

Figure 2. Flow chart of SA use for OHCA. The intervention group was defined as OHCA patients for which an alerted BS arrived to the scene performed 1) lifesaving gestures, initiation of chest compressions, or shift with a first bystander; 2) retrieve and use of an AED, 3) or both. The control group was defined as OHCA patients for which 1) BS did not respond, 2) some BS responded but none arrived, and 3) BS arrived on the scene did not perform action. BS = Bons Samaritains; OHCA = out-of-hospital cardiac arrest.

acknowledged and accepted, prompting the responding BS to rush to the site of OHCA (Figure 3). Most responding BS were young experienced men: two of three of them reported having previously performed chest compressions in real life, and three of four had completed more than 60 hours of first aid training (Table 1).

Upon identification and activation, a total of 137 BS did arrive on site. Approximately 37 of them did not perform CPR as they arrived after the BLS team (Figure 3). Two factors were associated with BS arrival on site prior to the BLS team: 1) a shorter distance between BS and the patient (median distance 350 meters vs. 500 meters, $p < 0.001$) and 2) direct phone contact with the chief dispatcher ($p = 0.02$; Table 2). Among the 100 BS who did arrive before the BLS team, 52 attempted lifesaving maneuvers and/or used an AED for 46 patients allocated to the intervention group (Figure 3).

Outcomes

Patients managed with SA were more likely to demonstrate ROSC upon hospital admission (48% vs. 23%, $p < 0.001$). A map of all OHCA events leading to SA activation is shown in Data Supplement S1,

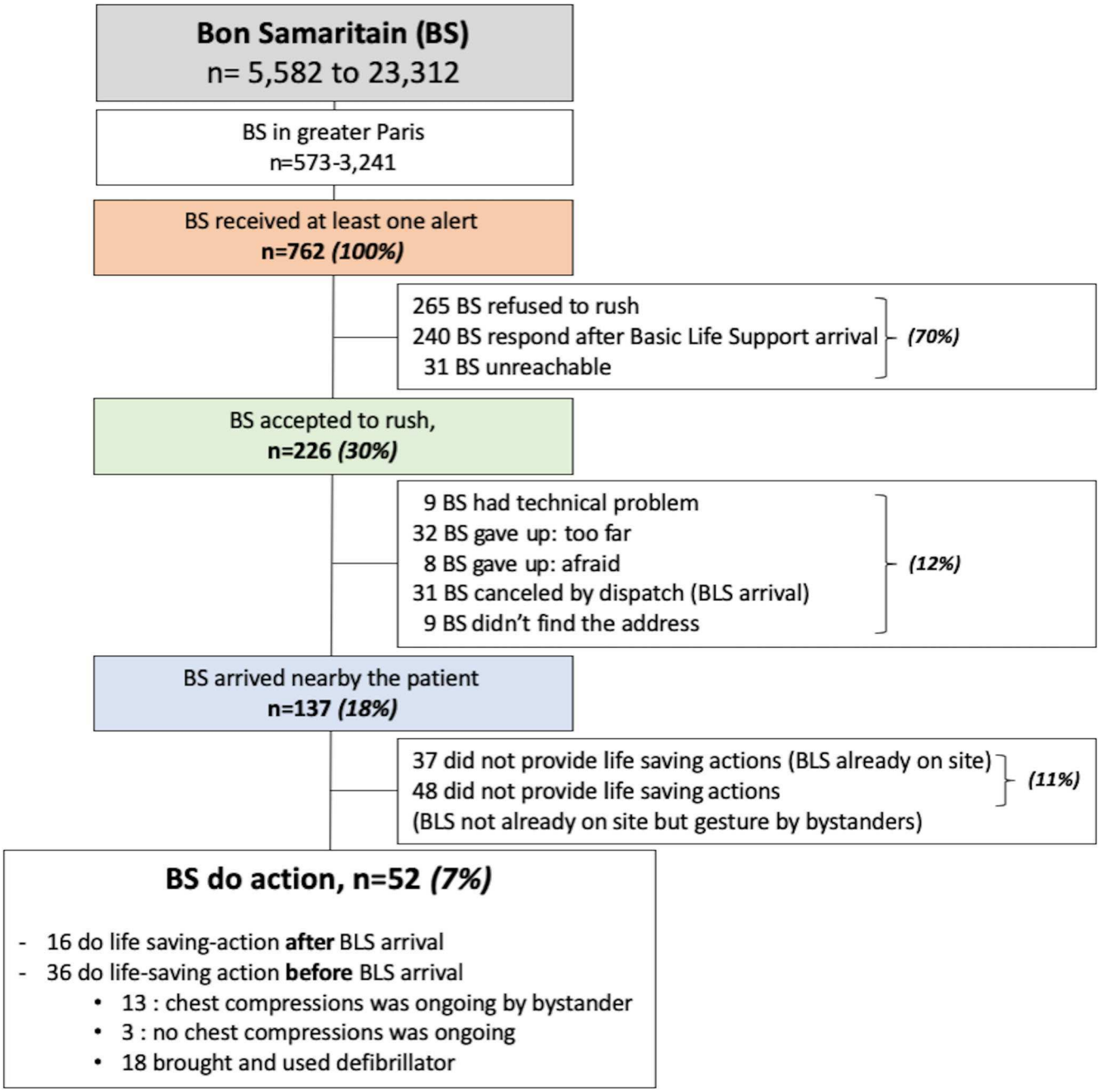

Figure 3. BS activation, response and actions. BS = Bons Samaritains.

Table 1
Characteristics of BS Who Agreed to Intervene (n = 210)

Age (years), median [25th–75th]	29.0 [24.0–37.2]
Male	164 (78)
Job	
Police and custom officers	8 (4)
Manual occupation	26 (12)
Students	26 (12)
Firefighter	34 (16)
Higher and intermediate occupations	44 (21)
Healthcare professionals	47 (22)
Others	25 (12
Regular first aid practice	
First aid association*	113 (54)
First aid level (hours of training)	
Life-saving gesture initiation (2 hours)	8 (4)
First aid level one (8 hours)	15 (7)
Health/security at work (15 hours)	17 (8)
First aid team one (35 hours)	19 (9)
First aid team two (one + 28 hours)	91 (43)
First aid team leader (two + 100 hours)	34 (16)
Nurse	13 (6)
Doctor	13 (6)
OHCAs supported before alert and notification	
0	69 (33)
1	29 (14)
2–10	36 (17)
>10	76 (36)

Data are reported as n (%) unless otherwise specified.
BS = Bons Samaritains; OHCA = out-of-hospital cardiac arrest.
*16 BS rushed twice.

Figure S1. The figure illustrates the distribution of cases allocated to the control group (blue dots) and the intervention group, whether lifesaving maneuvers were attempted (green dots) and/or an AED was used (red dots).

Among patients managed with SA, the survival rate on hospital discharge was greater in the intervention group than in the control group using univariate statistics (35% vs. 16%, p = 0.004; Table 3). With multivariate statistics with propensity scoring and SL methodology, 42 patients in the intervention group were matched to 72 patients in the control group with a variable ratio, ranging from 1:1 to 1:3. Counting replacements, controls were matched between one and 13 times. The final matched sample was balanced, except for variables describing the place of cardiac arrest (Data Supplement S1, Table S2). Using the final matched sample, logistic regression showed that survival on hospital discharge was associated with the following factors: 1) a shorter time between emergency call and BLS team arrival (adjusted OR for each elapsed minute = 0.99, 95% CI = 0.98 to 0.99, p < 0.01) and 2) allocation to the intervention group (adjusted OR vs. the control group = 5.9, 95% CI = 2.12 to 16.54, p < 0.001).

DISCUSSION

To the best of our knowledge, this report for the first time demonstrates the benefits of MST on survival following OHCA. Once deployed in Greater Paris, the SA application allowed not only to quickly identify nearby trained first responders, it also facilitated access to an AED. The 35% survival rate we observed in the intervention group is consistent with expected improvements previously anticipated elsewhere when using similar technology.[26,27]

Within a single year, we were able to show that SA activation was associated with a better outcome after OHCA, especially when the event took place during the daytime. Surprisingly given the novelty of the technology, several nearby first responders were alerted upon SA activation in more than 75% of cases. Those who responded in time to start or continue BLS on site before the presence of a full medical team nearly doubled the life expectancy of OHCA patients. Accounting for several confounding factors, we estimated that SA activation can lead up to a sixfold survival increase when trained first responders willing to start BLS are identified within 500 meters of an OHCA event.

The results of this real-life experiment may not be totally unexpected, as SA aims to facilitate early high-quality CPR and early defibrillation, two well-known predictors of successful outcome following OHCA.[18,28] Our results are observed in the most unfavorable context to highlight a difference between the groups. The OHCA patients for whom SA was activated were indeed already the one with the best prognostic, that is, witnessed arrest, in a public space and during daytime, already receiving bystander chest compression and optimized dispatch. However, our results should be further studied in different unfavorable settings to demonstrate widespread applicability.[26] For example, it is unclear whether SA activation remains beneficial in unfavorable circumstances (e.g., the cardiac arrest is not witnessed, is not followed by immediate CPR maneuvers, does not take place in a public area by

Table 2
Characteristics of BS Who Agreed to Intervene, According to Arrival Before or After BLS Team

	BS Arrival Before BLS Team (n = 44)	BS Arrival After BLS Team (n = 93)*	p-value
How many SA alert received before this alert?			
0	31 (70)	68 (73)	0.91
1	11 (25)	22 (24)	
2	2 (5)	3 (3)	
Day's period			
00:00–07:00	2 (5)	3 (3)	0.55
07:00–19:00	30 (68)	56 (60)	
19:00–00:00	12 (27)	34 (37)	
Location of BS when he received the alert			
Street	10 (23)	26 (28)	0.19
Residence	18 (41)	42 (45)	
Work	8 (18)	7 (8)	
Other	8 (18)	14 (15)	
Time period (seconds) between BLS notification and accepted alert†	77 [47–122.2]	116 [53-192.7]	0.053
Time period (seconds) between BS alert and BS acceptance to rush	40 [26.5–58.5]	39 [27–58.5]	0.91
Distance from BS location to scene‡	350 [220–500]	500 [350–725]	<0.01
Time period (seconds) between BLS alert and BLS arrival	480 [540–660]	480 [405–555]	0.08
BS call by chief-dispatcher before arrival	30 (89)	41 (44)	0.02
Gestures by BS‡			
None	8	77	<0.01
Chest compressions	16	8	
Bag ventilation	4	4	
Team leader§	1	2	
Use defibrillator	22	2¶	
Duration of chest compression before BLS arrival (n = 16)	140 [90–240]	—	

Data are reported as n (%) or median [25th–75th].
BS = Bons Samaritains; BLS = Basic Cardiac Life Support.
*Same time n = 30/after BLS n = 63.
†All time periods are reported in seconds; distance is reported in meters.
‡Some BS did more than one gesture.
§Minimalize hand-off time, organize team work, always emergency physician.
¶BLS defibrillator.

daytime).[18,28] In our cohort, 41 of 44 nearby first responders who arrived prior to the BLS team did not start CPR but took over from bystanders who initiated lifesaving maneuvers such as chest compressions. Additionally, a large percentage of first responders arrived on site after the BLS team, again highlighting the very short delay from emergency call to BLS team arrival in the Greater Paris area.

The question of the cost of such an application is essential. If the app is free for both users and dispatch centers, chief dispatchers must be trained to use it (2 hours of initial training and then 1 hour every 3 months for 9 months). The recruitment of BS was carried out thanks to our communication department whose main objective was to motivate Parisians to be trained in lifesaving gestures. No other expenses related to the application have been identified.

LIMITATIONS

We demonstrated an association between the use of MST and improved survival, without being able to assert a causal link. However, a causal relationship may be consistent with the scientific knowledge on OHCA physiopathology and the international guidelines recommending that BLS be realized as quickly as possible before arrival of a rescue teams.

Our analysis does not show that the app is effective in the general population, but that it has been effective for patients who have received the "treatment": we are

Table 3
Characteristics of Patients; OHCA, BLS, and EMS Features; and Patients' Outcomes

	Intervention	Control	p-value	Adjusted OR† [95% CI]
Characteristics				
No. of patients	46	320		
Age (years)	55 [44–71]	58 [43–71]	0.96	
Male	34 (74)	238 (74)	0.96	
OHCA circumstances				
Etiology of cardiac arrest			1.0	
Medical	42 (91)	291 (91)		
Trauma	4 (9)	29 (9)		
Place of cardiac arrest			<0.001	
Residence	5 (11)	118 (37)		
Street	25 (54)	126 (39)		
Public building, work, sport facility	16 (35)	76 (24)		
Collapse witnessed by bystander	36 (78)	189 (59)	0.08	
Chest compressions before BLS arrival	40 (87)	213 (67)	0.67	
Shock delivered by public defibrillator	9/22 (41)	—	—	
BLS				
Elapsed time before BLS arrival (minutes)	8 [8–11]	9 [7–11]	0.5	0.99 [0.98–0.99]
EMS				
CPR not attempted by EMS*	4 (9)	42 (13)	0.48	
Shock delivered by BLS or EMS	23 (50)	115 (36)	0.07	
Outcome				
Discharge alive from hospital	16 (35)	50 (16)	0.004	5.9 [2.12–16.54]

Data are reported as *n* (%) or median [25th–75th].
BS = Bons Samaritains; BLS = Basic Cardiac Life Support; OHCA = out-of-hospital cardiac arrest.
*Do not attempt resuscitation orders.
†Logistic regression with propensity score for complete cases.

interested in the ATT and not the ATE. We could have been limited to studying the association between the use of SA and improvement in chest compression delay. However, this delay is rather short and we would have been asked about its association with outcome. Similarly, the question of the quality of chest compressions and the association with outcome would have remained unanswered.

Several other experiments using similar MST applications have been conducted, mainly in Europe (Sweden, the Netherlands, Denmark, the United Kingdom, Switzerland) but also in Japan and Canada.[9–16] All the available evidence, including ours, issues from monocentric, nonrandomized studies, with the potential for exposure to confounding effects. The only published randomized study[8] on this MST solution conducted in 2015 was not designed to demonstrate any effect on survival. It did however demonstrate a significant increased ratio of BLS attempt by BS, and was underpowered to demonstrate an effect on survival. In 2018, such a randomized trial seemed to us unethical to perform, and we are surprised at the ongoing HeartRunner RCT (Copenhagen). We therefore rely only on data extracted from real life to measure and demonstrate a positive effect of the BS strategy, to increase their number and motivation, and launch the system in the whole country.

Future Directions

In summary, despite study design limitations, our results showing improved OHCA survival led us to consider using SA more systematically and working on several upgrades.[17–19] We believe the four following objectives can improve SA deployment and efficiency.

First, the number of trained BS should increase significantly. At the time of the study, we recorded 0.5 BS per 1000 inhabitants, very far away from the 5/1,000 ratio observed in Ticino, Switzerland; the 8/1,000 ratio observed Limburg, Netherlands; or the 10/1,000 ratio observed in Stockholm, Sweden.[11–13] Lately, the number of BS dramatically increased (51,252 in May 2019) locally in the Greater Paris area as well as globally at the national level where the system

is now available in 35 of 95 departments. Undoubtedly, this was the result of a coordinated campaign supported by the Greater Paris Region and Foundation Funds. That being said, monitoring and maintenance of a first responders' community is challenging and time-consuming. While one may consider awarding rewards each time a life is saved, one must also respect local ethical and legal boundaries such as those established by the French Parliament.[29] Ultimately, increasing the number of BS is most likely to positively impact remote, underserved medical areas.

Second, we have recently allowed nontrained volunteers to register in SA. At this time, we expect them to assist responders by making an AED available as quickly as possible. Some may opt to pursue BLS training, thereby increasing the pool of registered trained first responders. Although AEDs are currently only available at dedicated public hotspots, we are considering making AEDs available in mobile vehicles, such as police cars, taxis, or even post office vans.

Third, we have extended the activation of SA to indoor OHCA events, since those account for nearly 75% of cases in Paris and across the world. Although we aimed to investigate SA outdoors exclusively for pragmatic and regulatory reasons, several cases of indoor OHCA led to SA being mistakenly, yet successfully, activated. Given promising results after a single year of usage, we believe that it is now safe and necessary to extend the indication of SA activation to all OHCA events during daytime, as long as first responders are not putting themselves in danger.[30]

Fourth, we are working on fully automatic algorithms that will identify which OHCA management strategy is best suited, based on variables such as the number of nearby first responders available, their level of training, and the proximity of an SA-flagged AED.[27]

CONCLUSION

We hereby demonstrate that mobile smartphone technology can accelerate first responder dispatch and may most likely be instrumental to improving out-of-hospital cardiac arrest survival. This strategy might even be more critical in the future, with possibly worsened out-of-hospital cardiac survival due to increased delay to arrival to the victim, both because of traffic or because of desertification of a nonurban area. Furthermore, empowering people by registering them into a wide community of first responders may transform bystander-initiated cardiopulmonary resuscitation happening more by design than by chance. To overcome delay, the use of digital and personalized systems may finally improve rates of survival after out-of-hospital cardiac and realize the public health potential of bystander-initiated cardiopulmonary resuscitation.

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Supporting Information

The following supporting information is available in the online version of this paper available at http://onlinelibrary.wiley.com/doi/10.1111/acem.13987/full

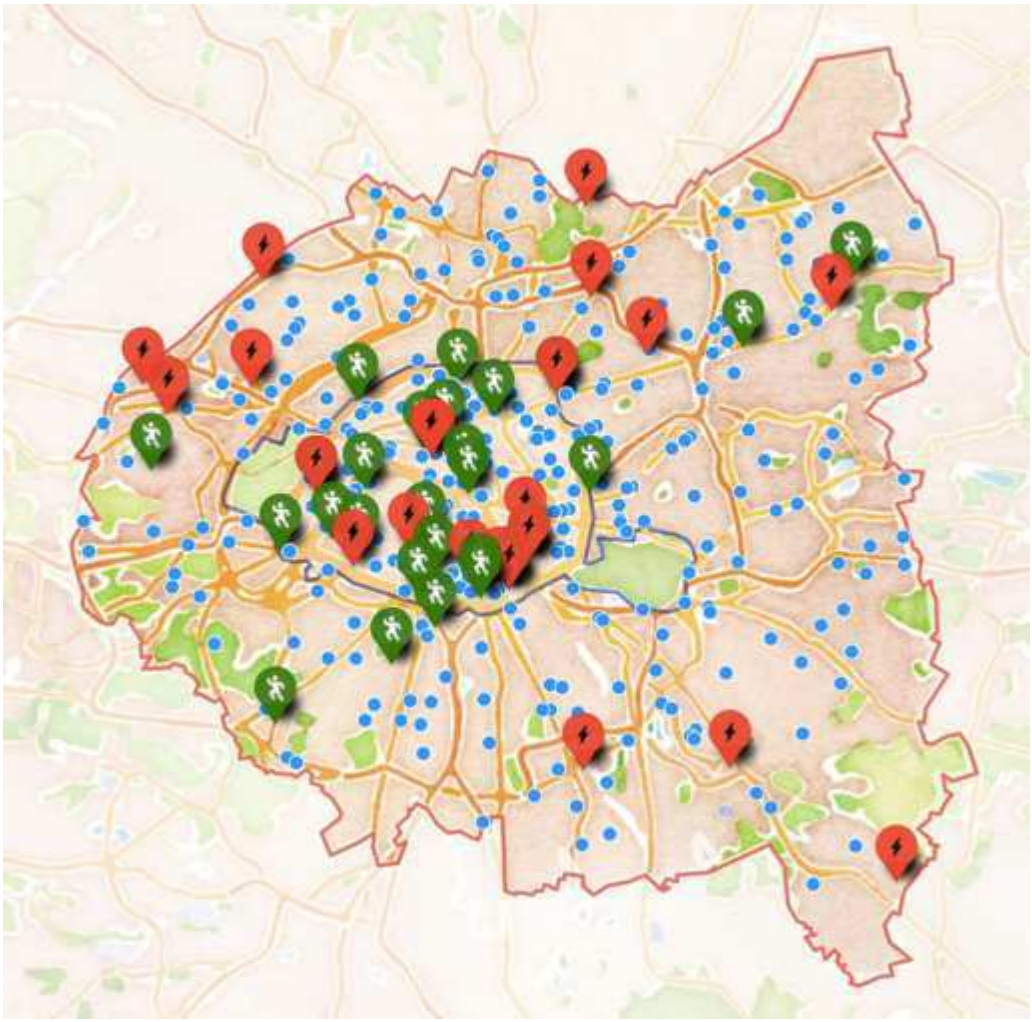
Data Supplement S1. Supplementary Material.

Supplemental material :

Video1. Video recording demo of the activation of the Staying Alive system at the Greater Paris Fire Brigade Despite all our efforts and while we believe that our video meets the specifications you are requesting, we have not been able to import our video into your submission site. You can download it here.

***Legend of* Video 1.** *This video shows the activation of Staying Alive on the dispatcher screen, with geolocalization of AED and Bons Samaritains, communication with him, routing to the scene, and telephone assistance.*

Additional Figure 1. Mapping of OHCA and Staying Alive activation



***Legend of* eFigure 1.** *Patients from the Control group are in blue points. Intervention group are in red points with lighting for AED use, and green points for life-saving actions performed by Bons Samaritains.*

Additional Table1. Characteristics of OHCA with or without Staying Alive activation

		Staying Alive not activated	Staying Alive activated	P Value
Characteristics				
No. of Patients		3737	366	
Age, years, median [25th – 75th]		71 [57-84]	58 [43-71]	< 0.001
Male		2156 *(57.7%)*	272 (*74.3%)*	< 0.001
OHCA circumstances				
Etiology of cardiac arrest				< 0.001
	Medical Trauma	3093 *(82.8%)* 282 *(7.5%)*	333 *(91.0%)* 33 *(9.0%)*	
Location of cardiac arrest				< 0.001
	Residence Street Public building, work, sport facility	3006 *(80.4%)* 430 *(11.5%)* 297 *(7.9%)*	123 (*33.6%)* 151 (*41.3%)* 92 (*25.1%)*	
Collapse witnessed by bystander		2101 *(56.2%)*	225 *(61.4%)*	< 0.001
Chest compressions before BLS arrival		1651 *(44.2%)*	253 *(69.1%)*	< 0.001
Public defibrillator use prior to BLS arrival		86 *(2.3%)*	22 *(5.9%)*	< 0.001
Basic Life Support (BLS)				
Elapsed time before BLS arrival median, seconds [25th-75th]		540 [480-720]	540 [420-660]	< 0.001
Emergency Medical Service (EMS)				
CPR not attempted by EMS		1699 *(45.4%)*	46 *(12.6%)*	< 0.001
Shock delivered by BLS or EMS		727 *(19.4%)*	138 *(37.7%)*	< 0.001
Transfer to Hospital with Return of Spontaneous Circulation		879 *(23.5%)*	178 *(48.6%)*	< 0.001

Additional Table2. The estimated quantity of interest is the average treatment effect on the treated group (ATT). This estimate answers to the subsequent question: "Would the outcome of unexposed patients to Staying Alive be different if they were exposed ?"

	Cases n = 42	**Weighted Control (n = 42)**	**P Value**
Age, years, mean (SD)	56.5 (19.2)	57.8 (15.7)	0.51
Etiology of cardiac arrest			0.4
Medical (%) Trauma (%)	38 (91%) 4 (9%)	40 (95%) 1 (2%)	
Location of cardiac arrest			0.04
Residence (%) Street (%) Public building, work, sport facility (%)	5 (12%) 23 (55%) 14 (33%)	4 (12%) 18.4 (44%) 19.6 (47%)	
Collapse witnessed by bystander (%)	34 (81%)	37 (88%)	0.18
Mean (SD) Yes (%)	9.3 (2.4) 15 (36%)	8.8 (2.7) 7.8 (19%)	0.4 0.09

***Legend of* Table2.** *Despite the use of the Super Learner, the intervention and control groups remained unbalanced for the location of cardiac arrest. The outcome model has been adjusted to account this residual imbalance. The propensity score matching methodology is based on the estimation of two models: first model for the propensity score estimation, second model for the outcome analysis. Each of these models may be misspecified with resulting bias. However, the use of the Super Learner improves the robustness of the propensity score estimation and the resolution method of the final model provides a robust variance. This doubly robust method provides unbiased estimates in the event of model misspecification (Li J, Handorf E, Bekelman J, Mitra N. Propensity score and doubly robust methods for estimating the effect of treatment on censored cost: J. LI ET AL. Stat Med. 30 mai 2016;35(12):1985-99.)*

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Letter to the Editor

Letter by Derkenne et al. regarding the article, "The use of trained volunteers in the response to out-of-hospital cardiac arrest — the GoodSAM experience"

We read Smith et al.'s article, "The use of trained volunteers in the response to out-of-hospital cardiac arrest — the GoodSAM experience," with great interest [1]. The authors describe the steps involved in implementing a smartphone app to alert individuals of nearby cardiac arrests so that they can start chest compressions and/or use public automatic external defibrillators (AEDs). Smith et al. also accurately identified the questions that line managers for emergency systems ask when faced with the deployment of such a smartphone app.

Since 2015, the Paris Fire Brigade has used a system very similar to GoodSAM within its area of rescue (800 km^2, 9 million inhabitants); this system is called the "Good Samaritan" (http://www.stayingalive.org/). Prior to this date, less than 50% of out-of-hospital cardiac arrests (OHCAs) received chest compressions, and these cases had a median "first call to AED switch-on" delay of 8 [5–11] minutes [2]. When we developed our own process, we identified three areas that were critical to its success, and we would like to address the following questions regarding these areas to Smith et al.

First, the overall effectiveness of this system, to a large extent, seems to depend on the likelihood that a "GoodSAM" responder will be located near an OHCA. Although anyone who holds a first aid diploma can register, in our area, we have just over 10,000 participants; most of them are in fact professional firemen or volunteers from first aid associations. We would like to know how the authors made 1500 GoodSAMs aware of their app. We would also like to know which populations these participants come from.

Second, there is the matter of the physical and legal protection of the good Samaritan participants. In France, lay rescuers are considered to be "occasional public service collaborators," which gives them some form of legal protection in the event of injury [3]. To meet legal requirements and fulfill our desire to start using this system as soon as possible, we initially made the choice of only alerting good Samaritans about OHCAs that occurred in public places (we did so manually via a call dispatcher, a method that differs from the one used in the GoodSAM system). We would like to ask the authors whether the GoodSAMs are alerted to events in private homes as well as in public places. Furthermore, like GoodSAM, our system allows good Samaritans to refuse requests. We would be interested to know the refusal rate that the London Ambulance Service observed in its experience.

Third, the search for an AED is fundamental, regardless of whether it is carried out jointly with or separately from the actions of a good Samaritan. Our system includes 4700 public AEDs. However, we encountered some difficulties in recovering the AED data due to the absence of any obligation for AED owners to declare their devices to the authorities. To mitigate this, the firefighters in our system organized a check of the implementation of these defibrillators. We would like to ask Smith et al. about the difficulties they encountered in collecting the AED data and in reporting the defibrillators' geolocations on the GoodSAM map.

Finally, the Paris Fire Brigade has collected data for the variables that Smith et al. cited. This will allow us to assess our progress accurately and to check the impact that our application had on survival in OHCAs.

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7.3. Automatic external defibrillator provided by unmanned aerial vehicle (drone) in Greater Paris: a real world-based simulation.

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Simulation and education

Automatic external defibrillator provided by unmanned aerial vehicle (drone) in Greater Paris: A real world-based simulation

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Abstract

Aim: To reduce the delay in defibrillation of out-of-hospital cardiac arrest (OHCA) patients, recent publications have shown that drones equipped with an automatic external defibrillator (AED) appear to be effective in sparsely populated areas. To study the effectiveness of AED-drones in high-density urban areas, we developed an algorithm based on emergency dispatch parameters for the rate and detection speed of cardiac arrests and technical and meteorological parameters.

Methods: We ran a numerical simulation to compare the actual time required by the Basic Life Support team (BLSt) for OHCA patients in Greater Paris in 2017 to the time required by an AED-drone. Endpoints were the proportion of patients with "AED-drone first" and the defibrillation time gained. We built an open-source website (https://airborne-aed.org/) to allow modelling by modifying one or more parameters and to help other teams model their own OHCA data.

Results: Of 3014 OHCA patients, 72.2 ± 0.7% were in the "no drone flight" group, 25.8 ± 0.2% in the "AED-drone first" group, and 2.1 ± 0.2% in the "BLSt-drone first" group. When a drone flight was authorized, it arrived an average 190 s before BLSt in 93% of cases. The possibility of flying the drone during the aeronautical night improved the results of the "AED-drone first" group the most (+60%).

Conclusions: In our very high-density urban model, at most 26% of OHCA patients received an AED from an AED-drone before BLSt. The flexible parameters of our website model allows evaluation of the impact of each choice and concrete implementation of the AED-drone.

Keywords: Out-of-hospital cardiac arrest, Unmanned aerial vehicles, Defibrillation, Simulation

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Introduction

The survival of out-of-hospital cardiac arrest (OHCA) patients depends on the ability of healthcare systems to provide a coordinated response between the Emergency Medical Dispatch Centre (EMD) and bystanders to provide chest compressions and defibrillation as soon as possible. This highlights the importance of the fundamental interaction between EMDs and bystanders for the first two links in the survival chain as noted in the 2015 European Resuscitation Council guidelines.[1–3]

Since 2015, a public access defibrillation program in Greater Paris has attempted to improve early defibrillation through the appropriate implementation of public automatic external defibrillators (AEDs) and the use of mobile responders. Nevertheless, only 4% of OHCA patients benefit from AEDs before the arrival of the Basic Life Support teams (BLSts).[4–8] This minor proportion, and an average BLSt arrival time of 10 min, accounts for why the recommended delay of less than 3 min between collapse and defibrillation[9,10] is rarely achieved.[8]

AED-equipped drones appear to be a potential solution for faster access to defibrillation.[11] Several studies have evaluated their reliability[12–15] and effectiveness in sparsely populated areas.[13,14,16–18] However, there is no evidence that AED-drones provide faster access to defibrillation than BLSts in high-density urban areas. Similarly, current models do not incorporate the constraints of EMDs sending drones (delay, OHCA detection rate) or the constraints of witnesses reaching them.[19]

Simulating the dispatch of drones in an area covered by a rescue system is complicated. Nevertheless, it is an essential preliminary step to ensure their effectiveness with administrative, political, and financial authorities. The aim of the present study was to evaluate the overall effectiveness of a system using simulated AED-drones to hasten access to defibrillation for OHCA patients in a high-density urban area. The present study also aimed to develop a simulator that is easy to access (website) and set up and can be used by other research centres.

Methods

Study design

We conducted a computerized simulation study. For each OHCA included in this study, we ensured that the characteristics were consistent with the dispatch of a drone and compared the actual delay of the BLSt to provide an AED with the delay obtained from a simulation of an AED being sent by drone. We estimated the time differential for the two delivery modes and classified each OHCA based on whether this delay was positive (AED-drone first) or negative (AED-BLSt first). Patients for whom the simulation did not authorize any drone to fly were assigned to a third group: no drone flight. The proportion of events in the AED-drone first, AED-BLSt first, and no drone flight groups was the main endpoint. The delays in the three groups were the secondary endpoint. We also described and compared the Utstein characteristics of the three groups and analysed the potential explanatory variables to determine which may be associated with the dispatch of a drone and a delay in AED delivery. Finally, we developed a website that allows our simulation to be carried out with different parameters and is available to other rescue systems that would like to perform simulations according to their own operational conditions.

Setting and patient data

The Greater Paris area covers 800 km^2 with 7 million inhabitants (density 7000−21,000 inhabitants/km^2), with a rescue system comprising a two-tier response system. At the EMD, the detection of an unconscious person triggers the dispatcher to send a first BLSt that, in the case of cardiac arrest, is joined by a second BLSt and an Emergency Medical System team (EMS). The dispatcher also starts telephone cardio-pulmonary resuscitation. Ambulances are selected from the available vehicles at the fire station closest to the event. Greater Paris has 23 main fire stations, 50 secondary fire stations, and 280 BLSts.

Patient data were sourced from the Paris Fire Brigade & Sudden Death Expertise Centre Registry, a prospective pre- and in-hospital population registry based on Utstein's style.[5,8,20] We included OHCAs that occurred during 2017 but excluded those managed with a public AED before the arrival of the BLSt, those in presence of EMS/BLSt, and those of traumatic cause.

Simulation parameters

The simulation algorithm was based on two different types of parameters (Fig. 1): those that authorized the flight of the drone and those that influenced its arrival time on site. The list of parameters was established based on the organization of the Parisian cardiac arrest chain of survival.

Go/no-go drone parameters

The algorithm did not authorize the simulation of an AED-drone in the case of no cardiac arrest detection at the EMD[5] or, for OHCA at home with a single witness, as the search for the AED would be a source of prolonged interruption of chest compressions (Fig. 1). Notably, this cause of hands-off time does not occur in public places, as the drone would drop the AED near the patient.[19] The drone was not authorized to take off when the outside temperature was outside the range of operation [−10 °C, +50 °C], if the horizontal sight was less than 200 m, if the wind was more than 50 km/h,[21] or if the intervention took place during the aeronautical night (from 30 min after sunset to 30 min before sunrise; different each day). For each cardiac arrest, the weather data of Greater Paris of the same day and time were used.

AED-drone delay parameters

For each OHCA, the BLSt was sent as soon as the dispatcher detected unconsciousness, but the drone was only triggered once abnormal ventilation was detected. As the average time between these two detections was 104 s at our EMD in 2017,[5] we applied this disadvantage when the drone took off compared to the departure of the BLSt. As for the allocation of drones in the fire stations, it was set at one unit per centre. After a drone took off, this fire station was considered unavailable for any new take-off for a period of 6 h. We have set trajectory parameters that promote safety and that we believe are the most plausible when the civilian authorities come to authorize drone flights in Greater Paris: vertical take-off and landing to limit low-flying time, and transit altitude 100 m above ground level to allow an emergency parachute to be opened. Depending on the model, the parachutes need up to 3 s to deploy. If the drone fails at a cruise altitude of 100 m, the parachute will open while the drone is still 56 m high, allowing the drone to slow down to the ground (or to the roofs of Parisian buildings, which are an average of 20 m high. Our simulated drone has the performance of commercial drones used in other

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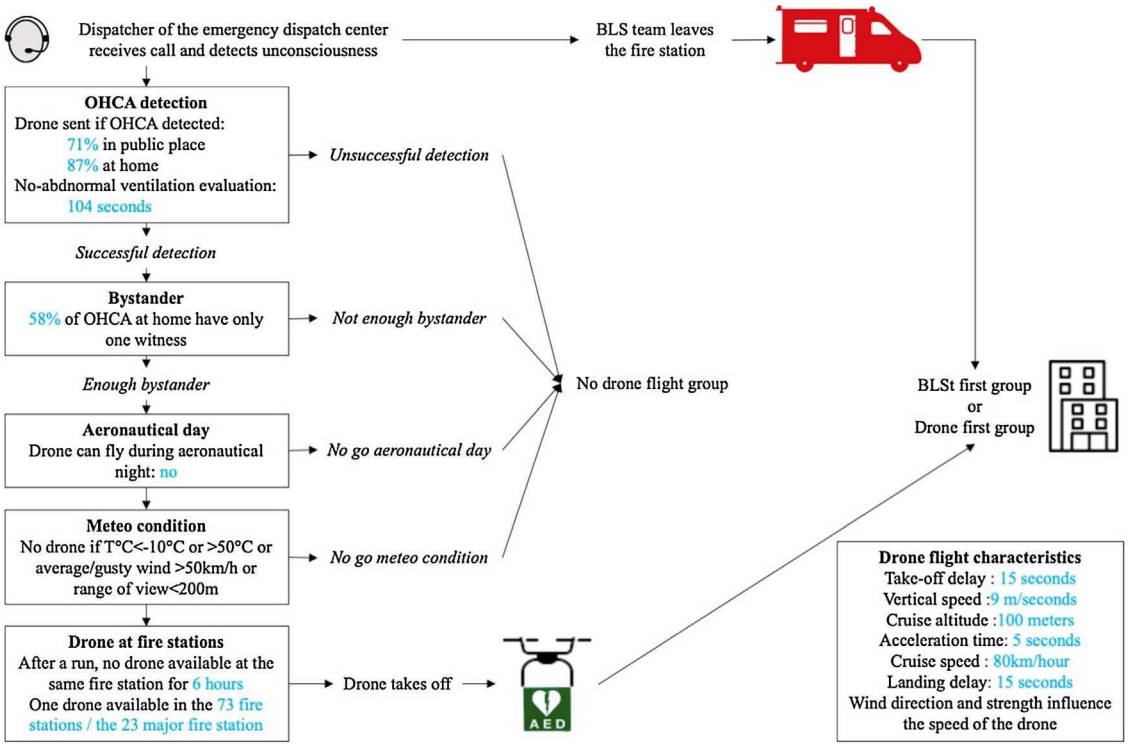

Fig. 1 – Simulation parameters.
Blue indicates that the parameter should be me modified on the simulation website. OHCA: out-of-hospital cardiac arrest; BLS: Basic Life Support team.

studies.[13,14,17] The transit trajectory is a straight line, and the horizontal speed is weighted by the speed and direction of the wind present on the same day at the same time in Greater Paris.[21]

Simulation strategy and statistical analysis

The simulation algorithm consisted of three successive steps. First, the values of the variables "OHCA detection" and "bystander alone" were not exhaustively available in the 2017 Sudden Death Expertise Centre Registry cohort. We randomly assigned these variables a "YES" or "NO" value in accordance with the proportions observed in a sample of the same cohort the same year.[5] Second, we formed two groups ("no drone flight" and "drone authorized") depending on whether the OHCA parameters authorized the take-off of the drone. For each patient in the "drone flight" group, we calculated the time of arrival of the drone and the differential value from the actual BLSt delay, after which the patient could be labelled either "AED-BLSt first" or "AED-drone first". We repeated the first two steps until the model converged (Appendix 1).

The estimators were the mean ± standard deviation for quantitative variables and the percentage for qualitative variables. The comparison of Utstein characteristics is given without p-values because the repetition of the model on an empirical convergence of the results artificially inflates the number of patients. The comparison of Utstein's variables uses the difference in means (95% inter-quantile interval). All calculations were performed using Python software (pandas, numpy, and geopy packages).

Ethical considerations

This simulation study received a positive notice from the French Anaesthesia & Intensive Care Society (IRB 00010254-2018-151). Individual data were anonymized before use, and their use complies with current French regulations.

Results

Patients and simulation data

The 2017 cohort of the Sudden Death Expertise Centre Registry registered 3515 OHCAs supported by a BLSt. Of these, 3014 met the inclusion criteria and could be included in the simulation (Fig. 2). Applying the chosen simulation parameters, the repartition of the

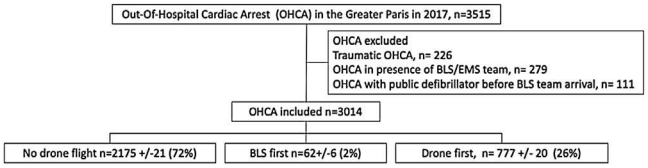

Fig. 2 – Flowchart.

OHCAs included 2175 ± 21 (72%) in the no flight drone group, 777 ± 20 (26%) in the AED-drone first group, and 62 ± 6 (2%) in the AED-BLSt-drone first group. When an AED-drone could be simulated, it arrived an average 190 ± 7 s before BLSt in 92.6% of cases (Fig. 3).

Influence of parameters on the model

Among the 2175 ± 21 OHCAs in the no drone flight group, 1172 ± 0 were related to the aeronautical night, 1238 ± 33 had only one witness present for OHCA at home, 506 ± 21 were considered to not be detected by the operator, and 5 ± 0 were related to the weather. There were two no-flight criteria for 843 ± 40 OHCAs, three criteria for 72 ± 8 OHCAs, and four for 1 ± 1 OHCAs. When a drone was authorized (n = 839), the nearest fire station no longer had a drone available (drone already in use within the previous 6 h) in 628 cases. The most frequently used fire station encountered this situation 20 times in 2017.

If the only modification to the parameters was the authorization for the drone to fly at night, the AED-drone first group increased from 777 to 1245 OHCAs (+60%; Fig. 3). If the only modification was to equip the 23 major fire stations (vs. all 73 fire stations), the AED-drone first group decreased from 777 to 680 (−12%) and the average arrival time of the drone increased from 190 to 271 seconds (+43%). If the OHCA detection rate in 2017 had been the same as that of our centre in 2018 (94% at home and 87% in public places),[5] the AED-drone first group would have increased from 777 to 888 OHCAs (+14%).

Utstein characteristics

The characteristics of OHCAs in the no drone flight versus drone authorized groups, and the AED-drone first versus AED-BLSt first groups are compared in Table 1. The Utstein characteristics of the drone flight group tended to be more favourable than those of the no flight group: more were witnessed by a bystander, more CPR was attempted by a bystander or EMS, more shocks were delivered, better survival.

Website

A website has been created in English and French at https://airborne-aed.org/ (Fig. 4). The site contains a description of the model and the different parameters that influence it. The simulation can be run using the standard parameters chosen in the present study (Fig. 1). Each parameter can be changed and two simulations run simultaneously and compared to evaluate the influence of the modifications. The model and website codes are available open-source via a GitHub repository (https://github.com/AlbaneMiron/drone-simulation). An additional plug-in allows implementation of the OHCA data (geolocation,

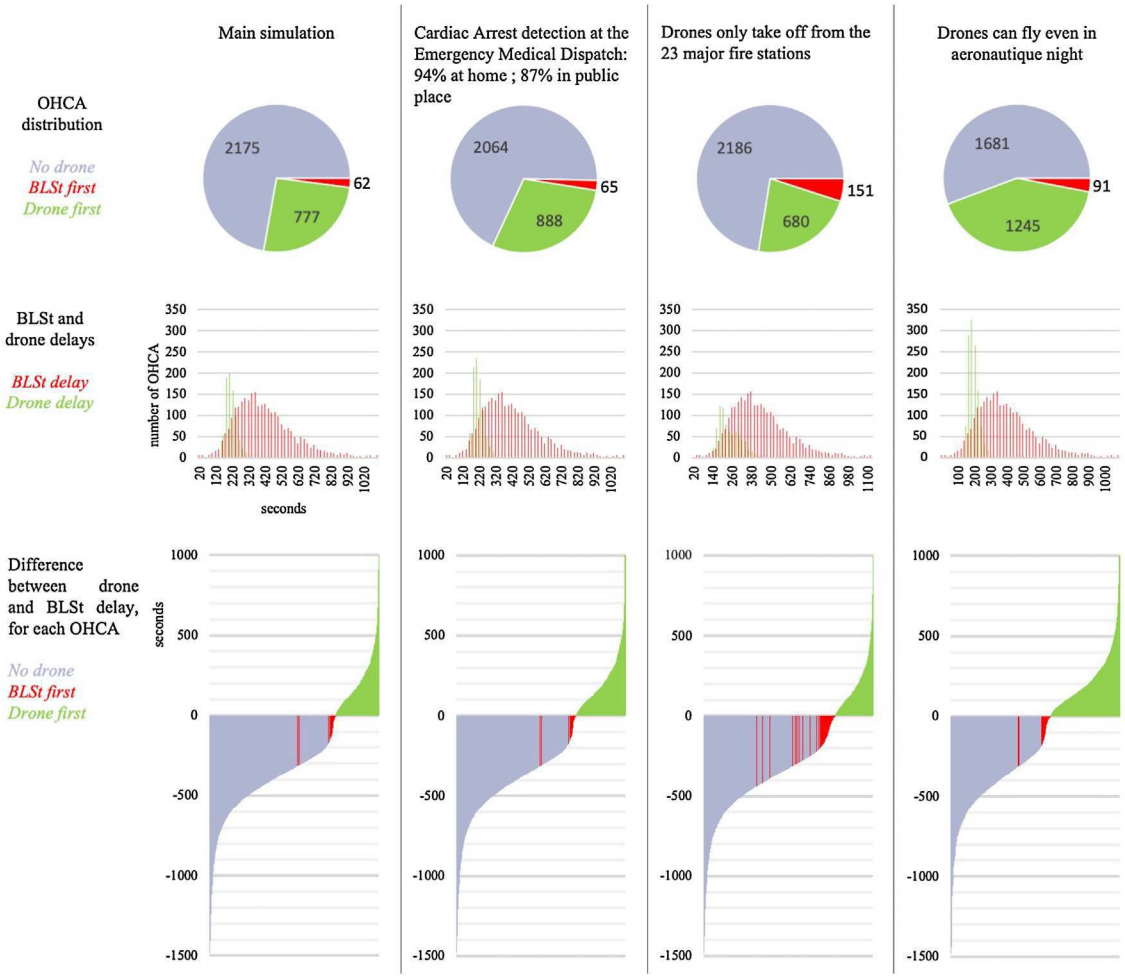

Fig. 3 – Out-of-hospital cardiac arrest (OHCA) distribution and delays between the "no drone", "AED-drone first", and "Basic Life Support team first" groups according to the main simulation.

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Table 1 – Utstein characteristics of the AED-drone first, BLS first, and no drone flight groups.

	Drone authorized vs. No drone flight			AED-drone first vs. AED-BLSt first		
	Drone authorized	No drone flight	Difference of the means [2.5°–95°]	AED-drone first	AED-BLSt first	Difference of the means [2.5°–97.5°]
Number (n ± SD)	839 ± 10	2175 ± 21	–	62 ± 6	777 ± 20	–
Mean age, years	67.8	68.3	−0.5 [−1.8 to 0.7]	67.9	66.4	1.5 [−1.8 to 4.9]
Gender male, %	61.8	58.9	3.0 [−0.5 to 6.3]	61.9	60.1	1.1 [−7.5 to 10.8]
Witnessed by bystander, %	55.3	51.0	4.3 [1.1 to 7.7]	55.7	50.6	5.1 [−5.0 to 14.9]
OHCA at home, %	58.5	83.5	−25.0 [−27.8 to −22.0]	58.9	54.0	4.8 [−3.4 to 14.2]
Median BLS team delay, s	425	442	−17.1 [−28.8 to −5.0]	446	158	288 [273 to 301]
CPR attempted by bystander, %	40.2	34.3	6 [2.3 to 8.8]	40.3	39.2	1.1 [−8.1 to 10.5]
CPR attempted by EMS, %	57.7	52.5	5.2 [1.6 to 8.6]	57.2	63.8	−6.6 [−14.3 to 2.7]
>1 shock delivered by BLSt, %	23.5	18.4	5.1 [2.4 to 7.8]	23.2	27.4	−4.2 [−11.9 to 3.3]
Admitted alive at the hospital, %	26.7	21.0	5.7 [3.2 to 8.4]	26.6	28.0	−1.3 [−9.4 to 7.0]
Discharge from hospital, %	5.8	3.4	2.4 [0.9 to 3.6]	5.7	7.0	−1.2 [−5.4 to 3.2]
Median drone delay, s	–	–	–	221	215	6.0 [−1.4 to 12.8]
Median distance covered by the drone, m	–	–	–	1,180	1015	165 [38 to 286]

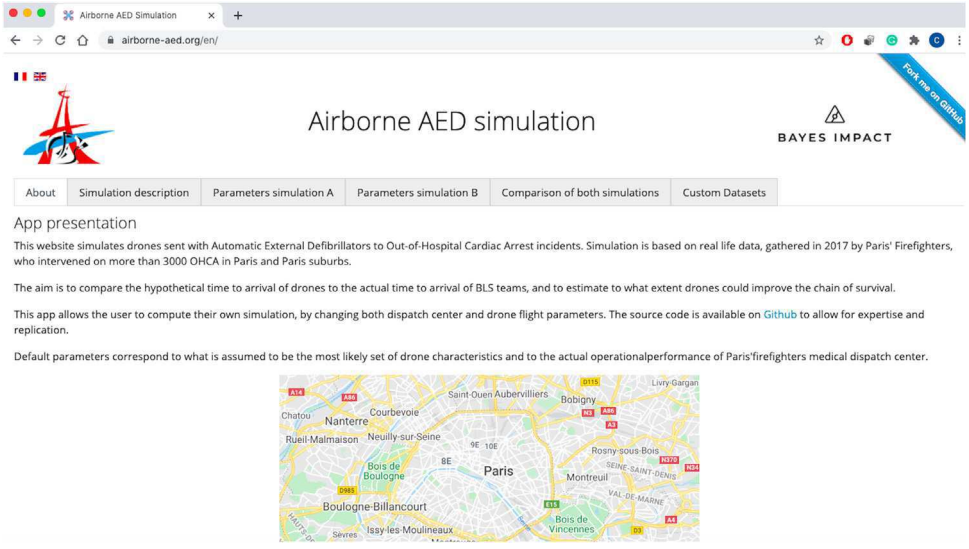

Fig. 4 – Screenshot of the simulation website.

date, and time), as well as AED-drone launch data so that other centres can run simulations more specific to their territory.

Discussion

To the best of our knowledge, this simulation is the first to study the effect of certain real-life parameters in high-density areas. The main result is that a quarter of OHCAs in Greater Paris could benefit from an AED delivered by a drone before the arrival of the BLSt. This is a significant proportion of such events and consistent with the literature, which reports that the proportion of OHCAs with AED-drone first decreases when the delay in the BLSt arrival decreases and the population density increases. Boutilier et al. reported that the AED-drone arrives before BLSt in 90% of cases (270 inhabitants/km^2), whereas Claesson et al. reported that the AED-drone arrives before BLSt in 93% of cases in rural areas (250 inhabitants/km^2) and 32% of cases in suburban areas (6000 inhabitants/km^2).[13,14,17] In contrast, the present study evaluated one of the densest cities in the world (7000–21,000 inhabitants/km^2) and found one of the lowest rates of AED-drone first.

Some parameters significantly affect the earliness of defibrillation. The option for drones to fly during the aeronautical night (e.g., later than 05:30 PM during part of the winter) should be considered from the very beginning when regulations are implemented (+60% OHCAs with AED-drone first). Currently, in France, the night flight ban is associated with the obligation of the pilot to control the drone in direct sight. However, the option supported in the literature is a flight without direct visual control during take-off and transit, and remote manual piloting assisted by the drone's camera during the landing phase or AED dropping with parachute or via remote system.[13,14,16,18] The no-go meteo/temperature criteria were almost never met in our simulation and seem to not be a concern in the greater Paris area. We did not model the results by changing the bystander alone at home rate because it was a parameter for which no corrective measures could be taken.

Simulations in the literature send a drone for 100% of OHCAs with simultaneous dispatch of the BLSt. This would mean that their EMD

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has 100% sensitivity (all OHCAs are detected) and specificity (as soon as the BLSt is sent, the EMD is certain of the OHCA diagnosis). In our real word-based study, in accordance with the recommendations of the American Heart Association,[22] the BLSt is sent as soon as unconsciousness is detected and the drone as soon as abnormal ventilation is detected. This takes an additional 104 s, which is the lead that BLSt has over drones. Despite this, BLSts rarely arrive before the drones, and only when their delay is very short.

In our model, we decided to integrate 15 real-life parameters that, a priori, could influence the earliness of defibrillation by AED drones. We cannot report all the results following the modification of one or more parameters due to to sheer volume. The creation of our open-source website, which allows modification of 13 of the 15 parameters, makes it possible to replicate our results, compare results with modification of one or more parameters, and analyse the results of centres that can implement their own characteristics (screening rate, bystander rate alone at home, etc.). This site is also intended for the decision-making authorities responsible for the deployment of drones.

Our model has strengths and weaknesses. First, the major weakness is the pure simulation of this research, even though we hope that we can convince our political authorities with such a model. Second, we opted for a rectilinear trajectory between fire stations and OHCAs. In reality, there are “no fly zones”, such as airports, government buildings, and prisons. Though the airports are located at the periphery of Paris with little influence on our results (other types of no-fly zones have a fairly small surface area). For the drone, avoiding these areas represents a minor trajectory deviation in relation to its speed. Greater Paris is a relatively flat zone, with very few buildings >50 m high. To replicate these results in cities with skyscrapers, users should set a higher cruising altitude; this has little influence on the flight duration of the drones (vertical speed 9 m/s). Another limitation is the possibility that some of the bystanders do not know how to use the AED, or not as quickly as the professional rescuers on the BLSt. The small size of the AEDs carried by drones seems to make their use sometimes less intuitive.[23] The increased deployment of public AED could also challenge early defibrillation by AED-drone but, despite many efforts, in greater Parispublic AED are still rarely used and sometimes out of service. Finally, our model does not include other parameters that could reduce the effectiveness of the drone-AED (e.g., drone sent on the very rare false-positive OHCA detection, drone failure, chest compressions stopped as the drone arrives but also political or security decisions that could limit the overflight of Greater Paris (Paris 2024 Olympic Games, G7 international conferences, International Paris Air Show)). All these reasons had led us not to extrapolate on the potential improvement in survival made possible by the early arrival of the drone.

Conclusion

In our very high-density urban model, at most 26% of OHCA patients received an AED from an AED-drone before BLSt. The flexible parameters of our website model allows evaluation of the impact of each choice and concrete implementation of the AED-drone.

Conflict of interest

None.

CRediT authorship contribution statement

CD, DJ, RK, BP & AM, designed the study, BF, VH, FL, RJ, FR & FB helped the acquisition of data, EM, OS & MS helped the analysis and the interpretation of data.

CD, DJ, AM, PC, BF, VH, FL, RJ, FR, EM, FB, OS, SL, MS, RK, BP drafted the article or revising it critically for important intellectual content and approved the version to be submitted.

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Disclosures

None.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.resuscitation.2021.03.012.

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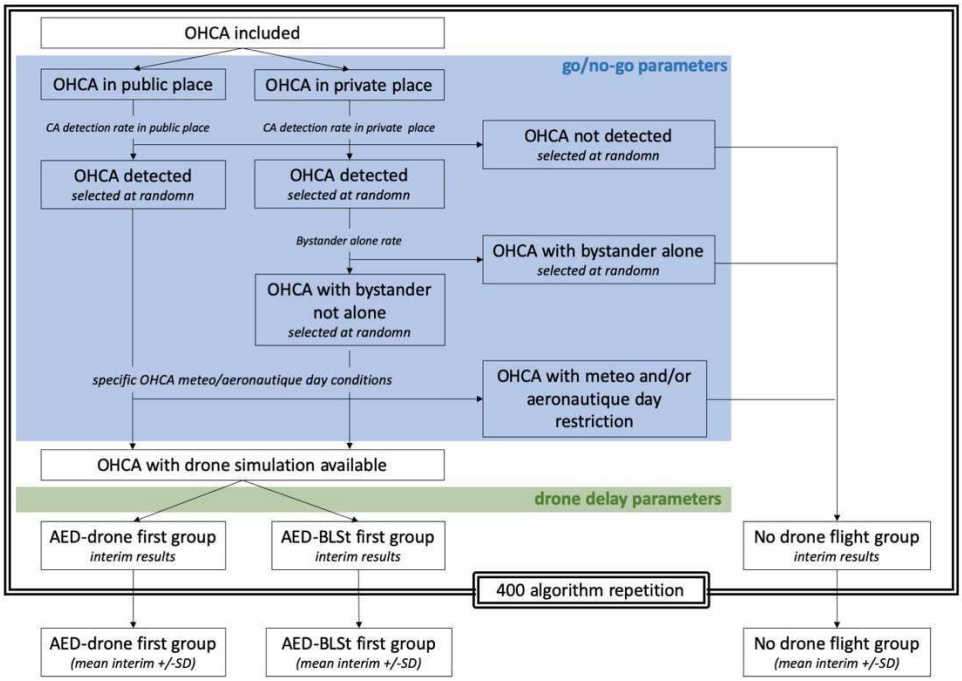

Figure 1; supplementary files de l'étude "drone-DSA"

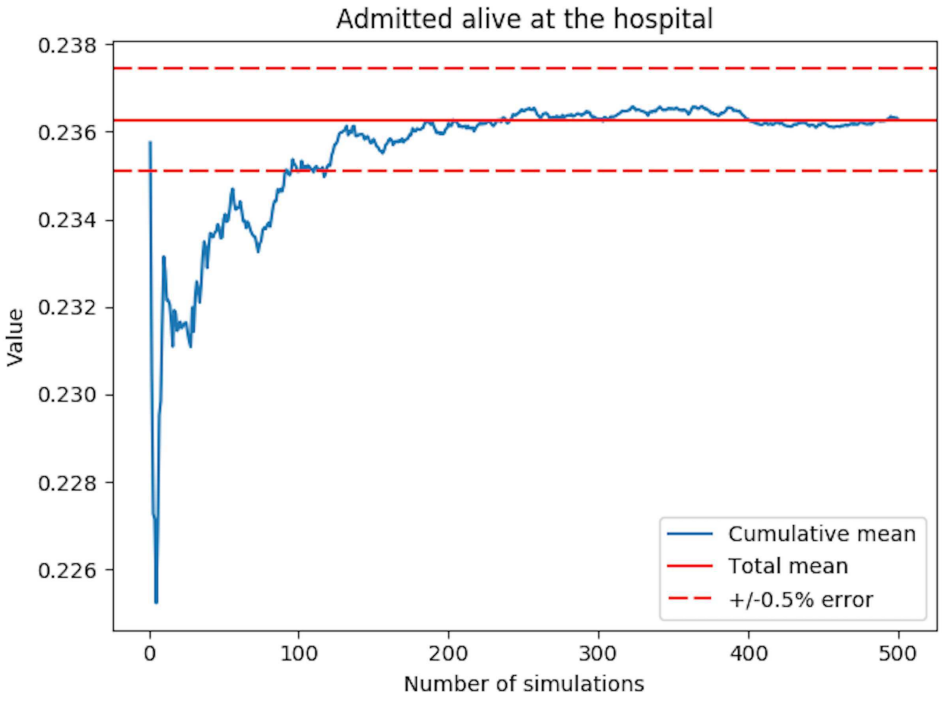

Figure 2: supplementary files de l'étude "drone-DSA"

7.4. Analysis During Chest Compressions in Out-Of-Hospital Cardiac Arrest Patients, A Before/After Study: The DEFI 2022 Study

Background: During out-of-hospital cardiac arrest (OHCA), an automatic external defibrillator (AED) analyzes the cardiac rhythm every two minutes; however, 80% of refibrillations occur within the first minute post-shock. We have implemented an algorithm for **A**nalyzing cardiac rhythm **W**hile performing chest **C**ompression (AWC). When AWC detects a shockable rhythm, it shortens the time between analyses by up to one minute. Here we investigated the effect of AWC on cardiopulmonary resuscitation (CPR) quality.

Method: In this before and after study, we compared a patient cohort treated in 2022 using AWC, to a historical cohort from 2017. The inclusion criteria were non-traumatic OHCA patients with a shockable rhythm at the first AED analysis. The primary end-point was the chest compression fraction (CCF), a measure of CPR quality. CCF was compared between groups, using a linear mixed model with an independent covariance matrix, considering study group, gender, and age levels as fixed effects, and incorporating a random intercept. Secondary end-points were cardiac rhythm evolution and survival, including survival analysis of non-prespecified subgroups.

Results: In 2017 and 2022, respectively, we registered 3538 and 3780 OHCAs, of which 355 and 377 met our inclusion criteria. The first consecutive 285 cases from each cohort were analyzed. Compared to the 2017 cases, among the 2022 cases, CCF was higher (77% [72–80] vs 72% [67–76]; $P<0.001$), VF recurrences were shocked more promptly (53s [32–69] vs 117s [90–132]), and patients spent less time in VF (109s [9–247] vs 185s [36–356]; $P<0.001$). Survival did not differ between the time periods ($P=0.85$ by log-rank test; adjusted hazard-ratio, 0.96 [95% CI, 0.78–1.18]), but was significantly higher in 2022 within the subgroup of cases with OHCA in a public place and a short time from call to AED switch-on ($P=0.009$; adjusted hazard ratio 0.85 [0.76–0.96]).

Conclusions: In non-traumatic OHCA, patients with AWC had an increased CCF, and decreased time in ventricular fibrillation. Survival was identical with or without AWC. However, AWC may be associated with increased survival for a subgroup of patients with a very good prognosis. ClinicalTrials.gov number: NCT04691089

Key Words: out-of-hospital cardiac arrest; refibrillation; algorithm; new technology

Introduction

Out-of-hospital cardiac arrest (OHCA) is among the leading causes of death worldwide, affecting around 350,000 people in the US each year. In most care systems, no more than 10% of patients survive, of whom 20% suffer significant impairment. The survival rate is only ~2% for non-shockable patients, and as high as 25–50% for shockable patients.[1,2]

Among patients with an initial shockable rhythm, over half experience ventricular fibrillation (VF) recurrence within the first minute post-shock.[3–5] Automated external defibrillators (AEDs) perform a cardiac rhythm analysis every two minutes.[6,7] Thus, there is a period during which the myocardium is likely to fibrillate and not receive a shock. A reduced one-minute interval between analyses would potentially limit VF duration, but an increased number of analyses could reduce the time devoted to chest compressions (CC). New-generation algorithms should allow the detection of VF recurrence without interrupting CC.[8–13]

In 2020, the American Heart Association reported that a critical knowledge gap was "whether artifact-filtering algorithms for ECG rhythm analysis during CC in a real-time clinical setting could decrease pauses in CC and improve outcomes".[6] In 2023, this finding was reinforced by the International Liaison Committee on Resuscitation.[14]

Since 2021, in Paris, prehospital basic life support teams (BLS) have been equipped with an AED using an "analyze whilst compressing" (AWC) algorithm.[9] If AWC detects VF during chest compressions, the AED shortens the cardiopulmonary resuscitation (CPR) phase by up to one minute, and launches the analysis phase.

In the present study, we aimed to assess the impact of a technology that can analyze electrical rhythm during CC. To this end, we compared the chest compression fraction (CCF) between an OHCA cohort resuscitated with this technology versus a control cohort treated with a conventional defibrillation algorithm. CCF is calculated as the cumulative time spent

providing chest compressions divided by the total time taken for the resuscitation, and is a strong determinant of resuscitation quality. Guidelines recommend a target rate of over 60%.[6] CCF reflects cerebral and coronary perfusion, and it is associated with patient survival,[15] as are pre- and post-shock pauses.[16]

Methods

Study Design, Setting, and Populations

We conducted a prospective, observational, before/after study to compare the characteristics of patients with OHCA managed by BLS teams using the AWC algorithm in 2022, versus a historical cohort from 2017 with OHCA managed using a conventional defibrillation algorithm. The study was conducted in the Greater Paris area, which has a population of 7 million, covers 800 square kilometers, and features a two-tier physician-manned emergency system.

During both time periods, BLS teams managed OHCAs according to the European Resuscitation Council 2015 guidelines.[17] They performed CC using an active compression-decompression device (ResQPump, Zoll, Chelmsford, MA, USA), and utilized bag ventilation and an AED model DEFIGARD Touch 7 (DGT7; Schiller Médical, France), which was precharged before analysis.[18] Subsequently, mobile intensive care units (MICU) assisted BLS teams on site with managing OHCA, performing tracheal intubation procedures, and administering medications, such as epinephrine and amiodarone. Patients who achieved a return to spontaneous circulation (ROSC) were transferred to the hospital.

In this study, we included OHCA patients over 12 years of age, with a shockable rhythm identified by AED at the first rhythm analysis. We did not include traumatic patients or those treated with an on-site AED before BLS arrival. Additionally, we excluded patients whose electrocardiographic tracings were illegible or disturbed by a pacemaker, those for whom no "analysis in presence of chest compression" had been performed (due to disconnection of electrodes, etc.), and those whose families refused to participate.

AED Algorithm

AED algorithms are designed to run cyclically, with a two-phase procedure: analysis phase and CPR phase. The analysis phase begins with the instruction to stop CPR, and includes the analysis itself, followed by shock delivery, and then the instruction to resume CC. During the CPR phase, chest compressions and ventilations are administered in a 30:2 ratio.

In 2017, cardiac rhythm "standard analysis" was performed at two-minute intervals (Figure 1).[19] In 2022, the AWC was used, with two aims: to reduce the interval between analyses, and thereby minimize the time to treat VF; and to avoid redundant minute-by-minute analysis that would lead to unnecessary analysis in the absence of refibrillation. To achieve these goals, the AWC algorithm performs iterative "analysis in the presence of CC". If an underlying shockable rhythm is detected, compressions are stopped for a "confirmation analysis", which may result in a shock recommendation. By design, the confirmation analysis (5-s duration) cannot occur within one minute following a standard analysis. Consequently, the CPR phases are designed to last between one and two minutes, depending on the results of ongoing analysis during CC.

BLS teams were not specifically trained to perform CPR with the new AWC algorithm; they were simply advised that this new algorithm would produce a variable time interval between analyses. They could not perform simulation-based training with the AWC algorithm because it requires CC to be detected via chest impedance, which is not possible with lower-fidelity manikins.

Data Collection

Clinical data were collected from the Utstein-based registers of the Paris Firefighters Cardiac Arrest Task Force, and the Paris Sudden Death Expertise Center.[1] Electrocardiographic data were extracted from the AED DGT7 electronic records, and included the electrocardiographic

traces, the impedance curve, and events related to the defibrillation algorithm (e.g., voice announcements). Using an automated process, the CCF was extracted based on events recorded by the AED. We manually annotated analysis periods—standard, in presence of CC, or confirmation—but also assessed the continuously read electrical rhythm (Figure S1–S7; S10).[20]

The 2022 cohort included patients managed from January 1, 2021 to January 31, 2022; and the 2017 cohort included patients from January 1, 2017 to December 31, 2017. The DGT7 AED was implemented in our center in 2016; thus, we decided to analyze the 2017 period because it was the first full year for which we had exhaustive defibrillation data. The AWC algorithm was implemented in our center in 2021; we analyzed the first year of its implementation.

Observation Windows

We limited our observations to analyzable traces within an observation window (OW), which was constrained by the intervention of rescue teams. BLS teams stopped CC in the event of ROSC, or the arrival of MICU, to allow intubation or manual rhythm analysis, even if interruptions were kept as short as possible.[21]

An OW was defined by the time interval from defibrillator activation to the earliest of three events: defibrillator switch-off, the 10th minute, or a presumed ROSC. Identification of ROSC was formalized by the presence of an organized electrical rhythm, a synchronized variation in thoracic impedance, and discontinuation of CC, which lasted until the end of the recording[22] (Figures S8 and S9).

Outcomes

We selected CCF as our primary end-point. Previous *in silico* studies have examined the performance of AWC (sensitivity and specificity), and found that it fulfils the performance goals recommended by standard and AHA guidelines.[9,23,24] However, it remains unclear whether performing a larger number of analyses using AWC, instead of the standard algorithm, would yield a significant reduction in CC delivered, and thus an improved CCF. CCF is a robust and replicable indicator, enabling comparisons of algorithms with CPR phases of varying lengths, thus establishing it as the preferred criterion for this study. We calculated CCF as the cumulative time spent providing chest compressions (hands-on duration) divided by the cumulative duration of the total complete cycles within the OW (Figures S11 and S12).

For secondary end-points, we focused on the prompt CCF (CCF during the cardiopulmonary phases). We also explored variables related to defibrillation, including the VF storm (defined as the interval between the first and last shock), and we documented the number and frequency of shocks, the time in refibrillation, and the interval between refibrillation and the subsequent shock. We carefully measured the pre-, post-, and peri-shock pauses; quantified the time allocated to analysis versus CPR phases within the OW; and determined the sensitivity and specificity of the algorithms for various cardiac rhythms. Finally, we conducted a survival analysis between the 2017 and 2022 cohorts, and then within non-prespecified sub-groups.

Sample Size Calculation

Previous non-published data from the Paris Fire Brigade demonstrated a mean thoracic compression fraction (CCF) of 70% (standard deviation, 14). To support the detection of a clinical difference between the two periods, we postulated that a five-point variation in CCF could have substantial clinical implications. based on a consensus among clinical experts on our research team. Therefore, if we consider an alpha risk of 0.05, a statistical power of 90%,

and a two-tailed test, our calculation based on the comparison of two means indicated that 259 subjects per group were needed to detect a five-point difference in CCF. With an estimated attrition rate of 10% (i.e., 26 per group), we determined that we required a sample size of 285 subjects per group, for a total of 570.

Statistical Analysis

We reported categorical variables as frequencies (%), and used Fisher's exact test for their comparison. Continuous variables were reported as medians [interquartile range; IQR], as they had no Gaussian distribution, and were compared using the t-test or the Mann–Whitney U test. Between-group differences were reported by the median difference [IQR]. Algorithm diagnostic performance is reported with a 90% confidence interval (CI) as reported by Kerber et al,[24] and was estimated by the method of Zhou et al, which is applied for clusters of multiple analyses per patient.[25] All comparisons were performed using two-sided tests, and a *P* value of <0.05 was considered to indicate statistical significance. To validate the comparability of the groups, we compared the main variables of interest: age, gender, time response of BLS teams, and BLS therapeutics.

We handled missing data by performing multiple imputation procedures, including variables under the assumption that missing values were missing at random (Table S1). All analysis were conducted on both imputed and non-imputed data sets. In the absence of significant differences between the observed and imputed values, we presented the imputed values (Figures S16–S20).

We applied propensity score matching, and used the inverse probability weighting (IPW) method to mitigate confounding effects and obtain reliable causal estimates of how different algorithms (standard and AWC) impacted the CCF. We selected covariates—age,

gender, location of cardiac arrest, time from call to AED switch-on, and witness status—based on their clinical relevance and potential to introduce confounding bias (Figures S13 and S14). We calculated the propensity score using a logistic regression model, in which the dependent variable was the period, and the independent variables were the covariates of interest. We verified the balance of covariates between the two algorithm periods, and found an effectively reduced bias across the observed variables (Figure S15).

We compared the CCF values between groups using a linear mixed model, considering study group, gender, and age levels as fixed effects, and incorporating a random intercept. Secondary end-points were studied using multilevel logistic regression modeling that was fitted using a generalized estimating equation method to account for time and patient clustering. Survival times were described using a Kaplan-Meier diagram and log-rank test, and fitted Cox proportional hazards regression models.

The statisticians (D.J., J.T., and V.H.) were blinded to the patient's time period. Analyses were conducted using R 4.2.2, and Stata software version 18.0 (StataCorp LLC) (Figure S10). Figures were generated using Prism 10.2.0 (GraphPad Software, Inc., Boston, MA, USA).

Ethics

This study was approved by the French Institutional Review Board of Tours (20.01291.202018), and is registered with ClinicalTrials.gov (number: NCT04691089). The surviving patients and their families were informed of the study terms and allowed to refuse participation.

Detailed descriptions of the materials and methods can also be found in the Supplemental Material.

Results

Patients

During the 2017 and 2022 periods, respectively, 3548 and 3780 OHCAs occurred in Paris and its suburbs, of which 362 and 377 met our inclusion criteria. We analyzed the first 285 consecutive patients from each time period (Figure 2). Table 1 presents their demographic characteristics. Table S1 describes missing data, and Table S2 describes excluded patients.

Primary Outcome

The CCF was significantly higher in 2022 than in 2017 (77% [72–80] vs 72% [67–76]; $P<0.001$) (Figure 3). Multivariate analysis revealed that this increase of CCF was associated with the following variables: the AWC algorithm, females, and public places (Figure 4).

Secondary Outcomes

Descriptions of Cycles

Compared to those in 2017, the analysis phases in 2022 were shorter (14 s [13–16] vs 21 s [19–24]; $P<0.001$ and more numerous (n=1208 vs n=883). However, during both time periods, 15% of the OW was dedicated to analysis phases ($P=0.51$). The pre-shock hands-off duration was 20s [18–23] in 2017, and 12s [10–15] in 2022 ($P<0.001$) (Table 2). Analysis phases can interrupt CPR phases during either CC or ventilation. This interruption occurred 91% during CC and 9% during ventilations in 2022, compared to 82% during CC and 17% during ventilations in 2017 ($P<0.001$).

Performance of Algorithms

In 2022, the global performance of the different types of analyses was 94.9% [93.7–96.2] for the sensitivity of coarse VF, 99.7% [99.4–99.9] for the specificity of asystole, and 99.3% [99.0–99.5] for the specificity of other non-shockable rhythms recognition. In 2017, the sensitivity for coarse VF recognition was 100%, and the specificity for non-shockable rhythm was 100% (Table S3).

VF Storm

The VF storm duration—defined as the time between the first and last shock—was similar in 2022 and 2017 (283 s [144–420] and 282 s [154–394]; P=0.99). In 2022, patients received more shocks at shorter intervals (0.86 shock/min [0.65–1.10 shock/min] vs 0.63 shock/min [0.56–0.83 shock/min]; P<0.001), and VF recurrences were treated twice as quickly (53 s [32–69] vs 117 s [90–132]; P<0.001). Between 2017 and 2022, the time spent in VF was reduced by around 40% (185 s [36–356] vs 109 s [9–247]; P<0.001), while the time spent in organized rhythm more than doubled (39 s [0–276] vs 88 s [13–336]; P<0.001) (Table 2, and Figure 5).

Survival

Survival at hospital discharge did not differ between 2017 and 2022 (hazard ratio 0.98 [95% CI, 0.81–1.19]; $P = 0.85$), even after adjusting for age, gender, location, bystander status, and time from call to AED switch-on (adjusted hazard ratio 0.96 [95% CI, 0.78–1.18]; $P = 0.71$) (Table 1, and Figure 6). However, we found improved survival in 2022 versus 2017 within a subgroup of patients who suffered from OHCA in public places and with a short time from call to AED connection (less than the median time of the study cohort; 12.5 min) (hazard ratio, 0.85 [95% CI, 0.76–0.96]; $P = 0.009$), even after adjusting for age, gender, and bystander status (adjusted hazard ratio, 0.83 [95% CI, 0.73–0.93]; $P = 0.002$) (Figure 6).

Discussion

Our present results demonstrated that implementing the AWC algorithm in adult OHCA patients with an initial shockable rhythm was associated with an increased chest compression fraction, compared to the historical algorithm. A higher CCF indicates that more CC were delivered during the observation windows.

There are two plausible explanations for our findings: more time was devoted to CPR in 2022 than in 2017, or more CC were delivered within the CPR phases. To explore the first possible explanation, the two algorithms differ structurally and the analysis phases were more frequent in 2022 than in 2017 (n=1208 vs n=883); however, this difference was offset by their shorter duration (14 s vs 21 s), resulting in a zero-sum result. Between 2017 and 2022, the relative median duration of the analysis and CPR phases remained identical (15%/84% in 2017 vs 15%/85% in 2022; Table 2). Therefore, the increase in CCF was not because more was time devoted to CPR in 2022 than in 2017.

Left with the second possible explanation, we assume that we measured increased time spent on CC during the 2022 CPR phases, which is evidenced by the higher prompt CCF during that year. This could be explained by two reasons, but it is challenging to determine their respective contributions. The first reason is based on a change in rescuer behavior, resulting in fewer ventilations and less downtime. The greater number of analysis phases in 2022 may have resulted in more chest compressors switching, and thereby limiting their fatigue and increasing their responsiveness in resuming CC after ventilation. Our measurement objectives included improved responsiveness due to shorter pre- and post-shock hands-off times. Previous publications have reported that shorter cycle time is related to increased CC quality.[26]

The second reason is related to the alternating mode of delivering 30 CC and two ventilations. CCF measures vary depending on whether the analysis phase interrupts the CPR

phase during CC or ventilation delivery. We observed that analysis phases more commonly occurred during ventilations in 2017 compared to in 2022 (17% vs 9%), and this effect was amplified by short cycles since one ventilation substantially impacted the ratio when calculating the CCF (Figure S22).

We have limited ability to compare our results with other studies, due to the innovative design of the AWC algorithm. One study investigated per CC analysis among patients in OHCA; however, the study design substantially differed from our present work.[8] The literature generally shows that a high CCF is associated with a better prognosis among patients with shockable rhythm; a CCF above 60% is recommended.[6,15]

Prolonged ventricular fibrillation (VF) is associated with myocardial damage, increased energy substrate consumption, and impaired recovery of contractile function—and these effects are exacerbated as VF duration increases.[27,28] AWC was designed to detect and treat recurrent and refractory VF at an early stage. Our 2022 study cohort exhibited a notably reduced VF duration, with the interval between refibrillation and subsequent effective defibrillation shock decreasing from a median of 117 s in 2017 to 53 s in 2022. This reduction of VF duration was observed to be equally redistributed in favor of organized rhythm and asystole episodes.

The 2022 cohort showed improvement of several variables associated with neurological outcome—including CCF, VF time, and pre-shock hands-off time. However, these benefits might have been undermined by a rise in the number of shocks administered, which could be harmful to the myocardium.[6,15,29–31]

The AWC algorithm has been developed and tested *in silico*, showing sensitivity and specificity performance in accordance with the standard and AHA guidelines.[9,23] We confirmed these results *in vivo,* showing overall sensitivity and specificity values in line with the limits recommended by Kerber et al,[24] except for ventricular tachycardia, as too few were recorded

(Table S3). The performances were lower in 2022 than in 2017. This may be explained by the inclusion of per-chest compressions analysis in the overall performance. The literature reports an acceptable reduction in sensitivity performance with per-chest compressions analysis algorithms.[8]

Several parameters indicate that BLS CPR was not disrupted despite the new algorithm with unpredictable analysis delays. The 2022 cohort exhibited low numbers of CC during analysis phases, a low number of recommended shocks not delivered, short peri-shock delays, and a constant CC rate.

Since 2005, most healthcare systems have used defibrillation algorithms with a fixed two-minute interval between analyses, but with a lack of high-level supporting evidence. Historically, the choice of two minutes was based on the onset of tiredness among BLS team members after two minutes of CC, and the fact that five cycles of CPR last approximately two minutes.[32–34] Studies have compared one-minute and three-minute intervals with the recommended two-minute interval, and have not highlighted any survival improvement,[35,36] and some guidelines have even suggested a one-minute or three-minute interval.[37,38] The two-minute interval is a compromise that is applied to all patients, regardless of their electrical rhythm.

Until very recently, no technology was available to adjust the cycle length according to the nature of the underlying rhythm. Theoretically, closer analysis enables earlier defibrillation, while more distant analysis benefits non-shockable rhythm by preventing unnecessary hands-off periods. To our knowledge, the AWC is the only algorithm that provides a time period that varies between one and two minutes, depending on the shockability of the underlying rhythm. We set a minimal time period of one minute, since in our center, 82% of recurrences happened within the first minute after the shock.[3]

AWC is a further step towards personalized OHCA treatment with AEDs, as shown by the time-smoothed distribution of shocks delivered during the 2022 period (Figure 5, panel A). AWC focuses on reducing VF duration, while other per-CC analysis algorithms are based on different choices.[8–13] Other promising approaches are currently being investigated, including electrical rhythm analysis during ventilation periods,[39] the probability of successful shock delivery,[12] and the probability of VF recurrence from the very first shock.[40]

The present study was not designed to assess patients' survival. Although CCF is associated with survival, and its increase is associated with a reduced duration of VF, we did not find any association between the improvement of CCF and patient survival. However, our results indicated that the AWC improved survival within a subgroup of patients who experienced cardiac arrest with an excellent prognosis, i.e. in public places, with the early use of an AED. These are patients described as being in the electrical phase, for whom refibrillation can find an exclusively electrical solution, unlike with patients in the circulatory or metabolic phase.[41]

Strengths and Limitations

Strengths of this work include the exhaustiveness of the data collection and the precision of annotations. Statistical methodology, via multiple imputation and propensity score matching, contributes to the robustness of the results. Our methodology is close to a quasi-experimental design, as described by Carter et al.[42]

This study has several limitations, including the before/after design, with a four-year interval between the two periods. However, we did not observe any changes in the BLS team's behavior during the five years between the two periods. It should be noted that the changes associated with COVID-19 did not affect the study period. The pandemic began after the 2017

cohort and ended before the 2022 cohort.[43] Additionally, we could not compare specific parameters, such as the time required to administer antiarrhythmias (e.g. amiodarone). The guidelines recommend antiarrhythmic injection after the third shock. This corresponded, at the shortest, to six minutes after cardiac arrest onset in 2017, but only three minutes in 2022. Consequently, the mean 10-minute delay from MICU arrival was a limiting factor in the timeliness of amiodarone administration. Another limitation may have been our decision to limit the observation windows. We chose to end the patients' observation when they had presumed ROSC, which invalidates the CCF measurement.[44] However, we chose three cumulative criteria to define presumed ROSC, which is more robust than what we found in the literature.[45]

Conclusions

In our study, the use of the AWC was associated with an improvement in the CCF. Moreover, the AWC might improve survival in a subgroup of patients with a very good prognosis.

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TABLES

Table 1. Baseline Patients Characteristics

	Period 2017 n=285	Period 2022 n=285	*P* value
Men, n (%)	212 (74)	231 (81)	0.07
Age in years, median [IQR]	58 [49–69]	60 [51–72]	0.27
Location, n (%) Home Public place Other	 151 (52.9) 112 (39.3) 22 (7.8)	 171 (60) 97 (34) 17 (6)	0.22
Bystander status, n (%) Not witnessed Witnessed and no CPR Witnessed and early lay-rescuer CPR BLS team-witnessed	 40 (14.0) 23 (7.9) 197 (69.1) 25 (8.8)	 10 (3.5) 41 (14) 208 (73.2) 26 (9.1)	<0.01
Minutes from call to AED connection, median [IQR], [a]	13 [11–16]	12 [10–15]	0.001
Seconds from AED connection to first shock, median [IQR]	24 [22–34]	19 [17–22]	<0.001
Epinephrine administration, n (%)	211 (73.9)	213 (74.7)	0.83
Survival at hospital admission, n (%)	177 (62.1)	170 (59.6)	0.55
Survival at hospital discharge, n (%)	72 (25.3)	79 (28.0)	0.49

[a] BLS team-witnessed patients are excluded.

IQR indicates interquartile range; BLS, basic life support; CPR, cardiopulmonary resuscitation; AED, automated external defibrillator; and AWC, analyze whilst compressing.

618 **Table 2.** Cardiopulmonary Resuscitation, Shocks, and Rhythm Characteristics

	2017 period	2022 period	*P* value
A Patients	n=285	n=285	
Chest compressions and pauses			
Chest compression fraction, %	72 [67–76]	77 [72–80]	<0.001
Prompt [a] chest compression fraction, %	83 [77–87]	88 [83–91]	<0.001
Hands-off max, s	22 [18–28]	18 [14–22]	<0.001
Prompt [a] hands-off max, s	8 [6–13]	7.9 [5–14]	0.20
Pre-shock hands-off time, s	20 [18–23]	12 [10–15]	<0.001
Post-shock hands-off time, s	4.7 [3.4–6.3]	3.8 [2.3–5.1]	<0.001
Peri-shock hands-off time, s	25 [22–29]	17 [14–20]	<0.001
Chest compression count between two analysis [b], n	195 [183–208]	145 [117–190]	<0.001
Cycle description in the observation windows			
Analysis [b] phase duration, s	21 [19–24]	14 [13–16]	<0.001
Cardiopulmonary phase duration, s	120 [120–120]	87 [64–122]	<0.001
Cycle duration, s	141 [139–144.1]	103 [81–132]	<0.001
Observation window (OW) duration, s	600 [421–600]	600 [440–600]	0.14
Analysis [b] phase duration/OW duration, %	15 [14–17]	15 [12–18]	0.51
Cardiopulmonary phase duration/OW duration, %	84 [83–86]	85 [82–88]	0.22
Ventricular fibrillation storm			
Time between the first and last shock delivered, s	283 [144–420]	282 [154–394]	0.99
Shocks per minute between first and last shock, n	0.63 [0.56–0.83]	0.86 [0.65–1.10]	<0.001
Number of shocks received, n (%)			<0.001
0 shock	5 (2%)	0 (0%)	
1 shock	101 (35%)	89 (31%)	
2 shocks	84 (29%)	62 (22%)	
3 shocks	53 (19%)	49 (17%)	
≥4 shocks	42 (15%)	85 (30%)	
Median number of shocks	2 [1–3]	2 [1–4]	<0.001
Time between shock and the next refibrillation [c], s	21 [11–37]	16 [9–35]	0.04
Time between refibrillation and the next shock, s,	117 [90–132]	53 [32–69]	<0.001
Time between refibrillation and the next efficient [d] shock, s,	122 [92–136]	57 [34–76]	<0.001
Resuscitation quality			

Chest compression rate per min, median	114 [111–118]	114 [112–119]	0.47
At least one shock recommended not delivered, n (%)	11 (4%)	6 (2%)	0.22
Rhythms in the observation windows			
Time spent in shockable rhythm, s, in organized rhythm, s, in asystole, s,	 185 [36–356] 39 [0–276] 72 [12–229]	 109 [9–247] 88 [13–336] 88 [13–335]	<0.001
Time spent in shockable rhythm/OW duration, % in organized rhythm/OW duration, % in asystole/OW duration, %	 31 [6–59] 7 [0–46] 12 [2–38]	 18 [2–41] 14 [0–58] 15 [2–56]	<0.001
B Analysis	n=883	n=3506	
Analysis type, n (%) *Analysis during the CPR phase.* Analysis in the presence of CC *Analysis during the analysis phase* Standard analysis Confirmation analysis Other analysis (canceled, etc.)	 not existing 883 (100%) not existing 0 (0%)	 2265 (65%) 576 (16%) 632 (18%) 33 (1%)	*N/A*
Presence of chest compression during the analysis phase, n (%)	12/883 (1%)	25/1241 [b] (2%)	0.25

All data except "At least one shock recommended not delivered" and "analysis type" are presented as median [interquartile range]. For the variables with repeated measures, the value shown in the table corresponds to the median of the individual medians. CPR indicates cardiopulmonary resuscitation, and CC, chest compressions.

[a] Prompt indicates "in the cardiopulmonary phase of the cycle".

[b] All types of analysis except "analysis in the presence of CC".

[c] Persistent fibrillation, defined as ventricular fibrillation during 5 seconds post-shock, is excluded.

[d] Efficient shock means cessation of shockable rhythm 5 seconds after shock delivery

FIGURES

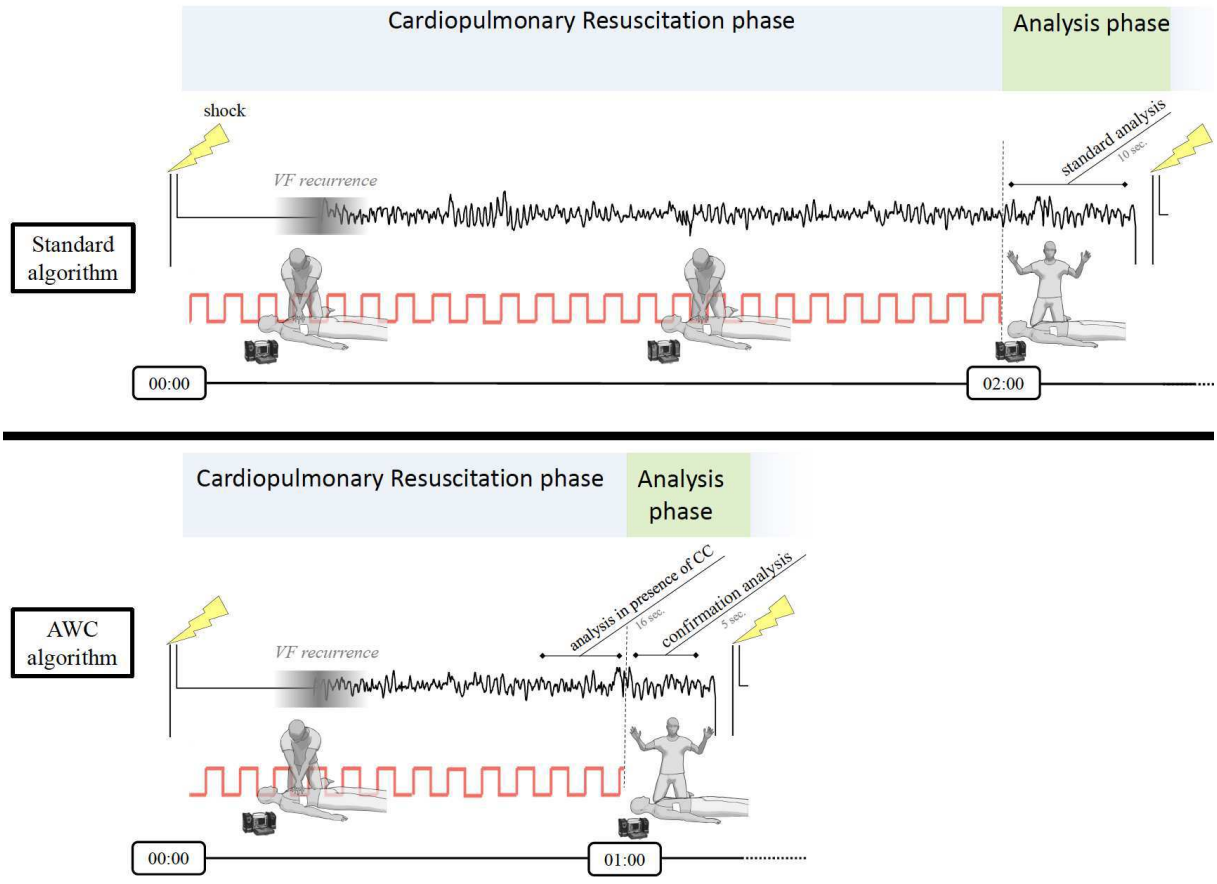


Figure 1. AED algorithms. AWC algorithm can lead to a confirmation analysis, which may shorten the duration of cardiopulmonary resuscitation if an underlying shockable rhythm is detected. AED indicates automated external defibrillator; and AWC, analyze whilst compressing.

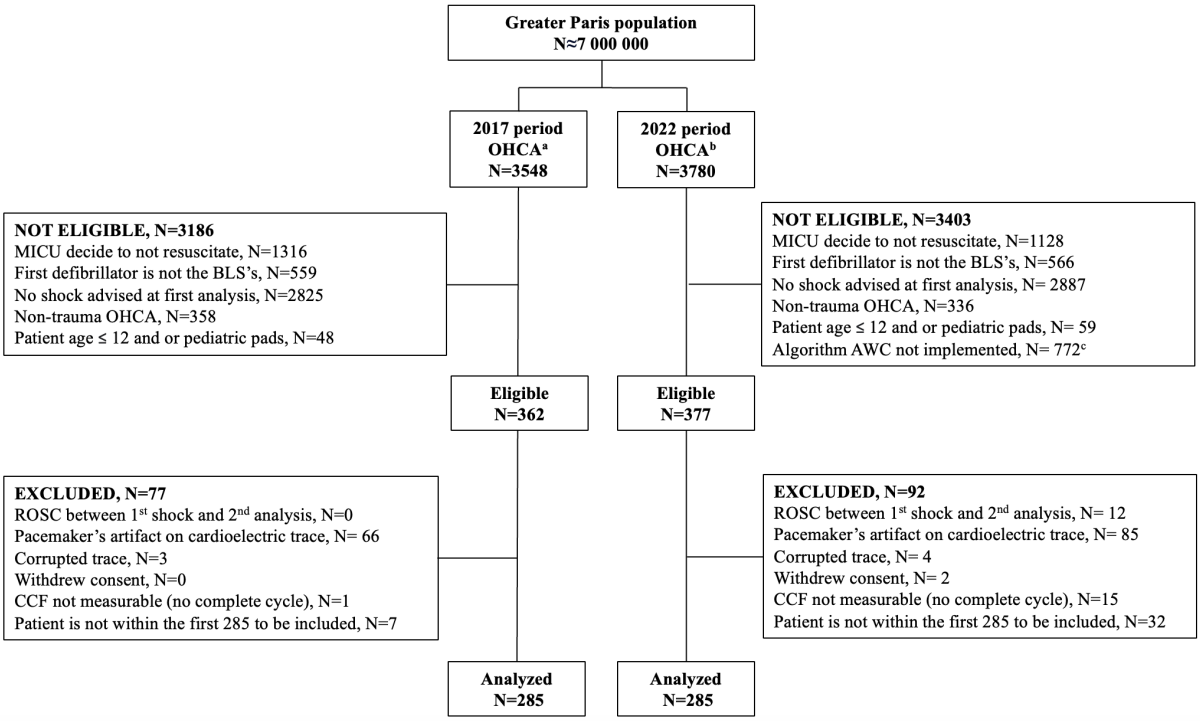


Figure 2. Flowchart.

[a] From January 1, 2017 to December 31, 2017.

[b] From January 1, 2021 to January 31, 2022.

[c] Gradual implementation in our 380 defibrillators over 5 months.

Some patients may have several reasons for non-inclusion or exclusion. BLS indicates basic life support team; AWC, analyze whilst compressing; CCF, chest compression fraction; MICU, mobile intensive care unit team; OHCA, out-of-hospital cardiac arrest; and ROSC, return of spontaneous circulation.

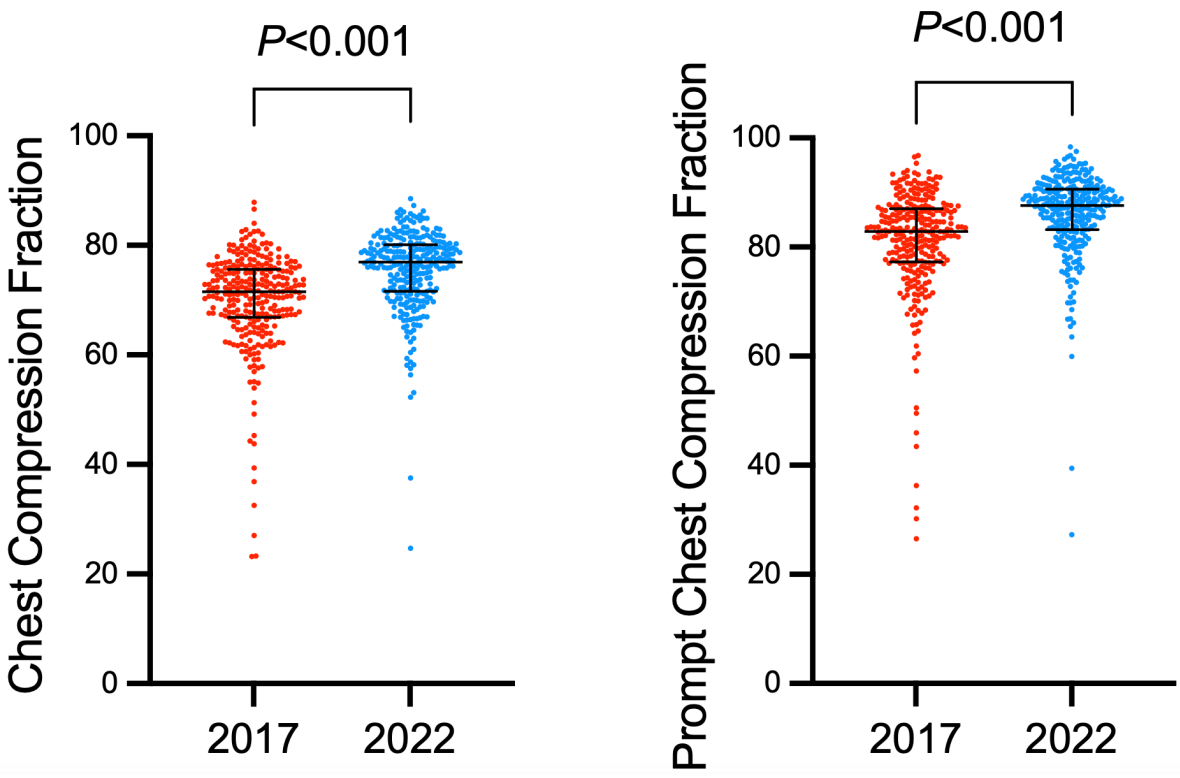


Figure 3: Chest compression fraction (CCF) and prompt CCF according to time period.

Prompt indicates "in the cardiopulmonary phase of the cycle".

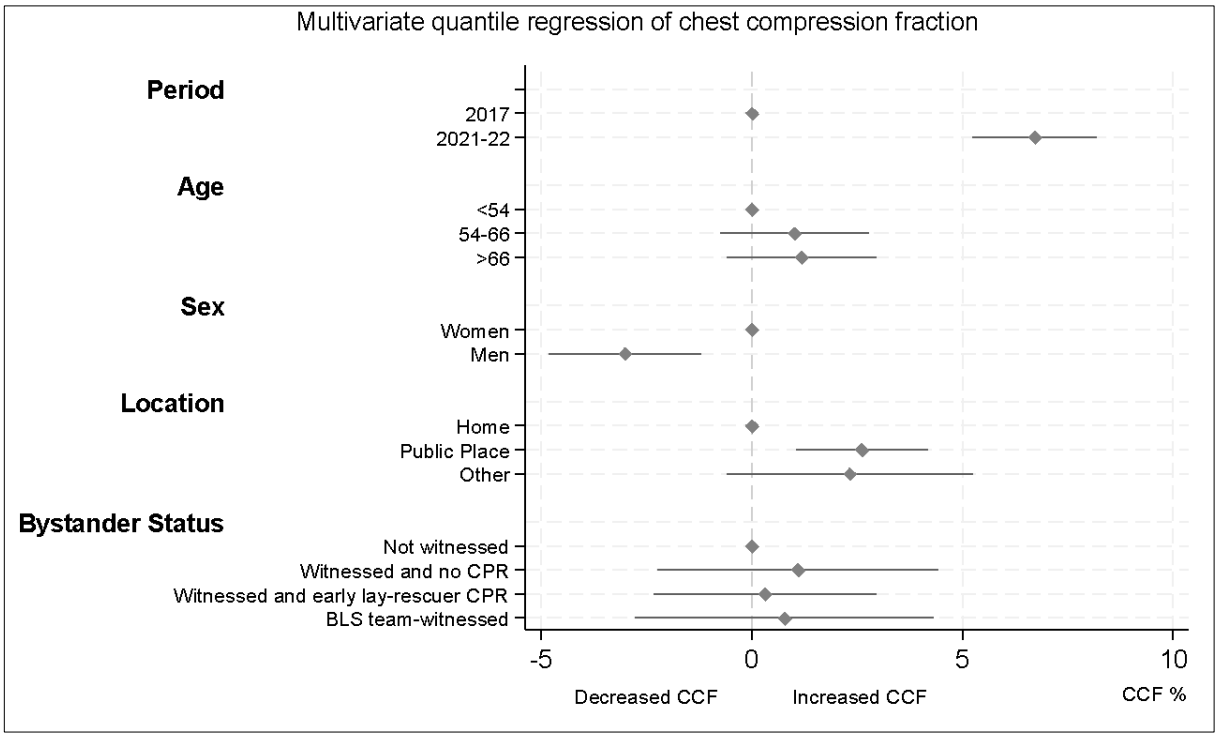


Figure 4. Forest plot and multivariate analysis of chest compression fraction. The forest plots represent the coefficients and their 95% confidence intervals resulting from quantile regression modeling. For each variable, the CCF value of a given category corresponds to the gain or loss in % CCF compared with the reference category. CPR indicates cardiopulmonary resuscitation; BLS, basic life support; and CCF, chest compression fraction.

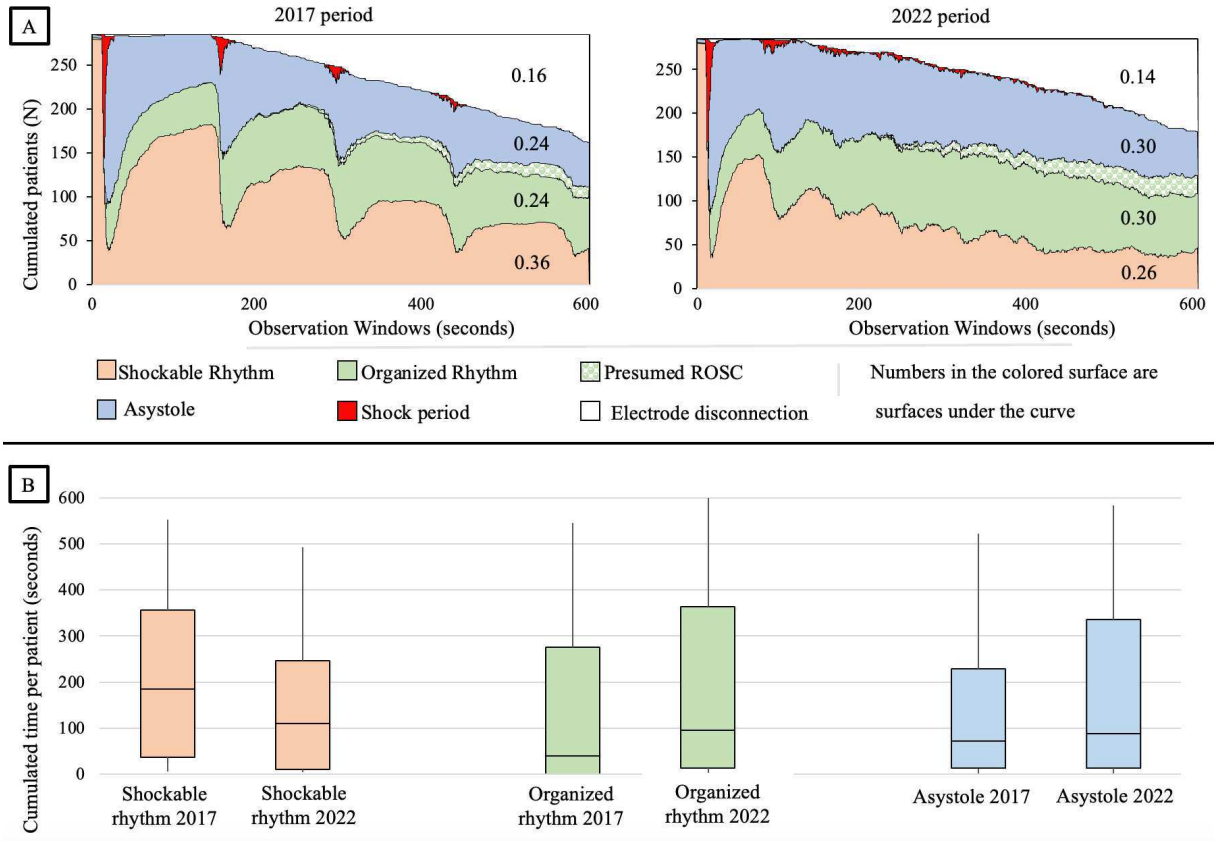
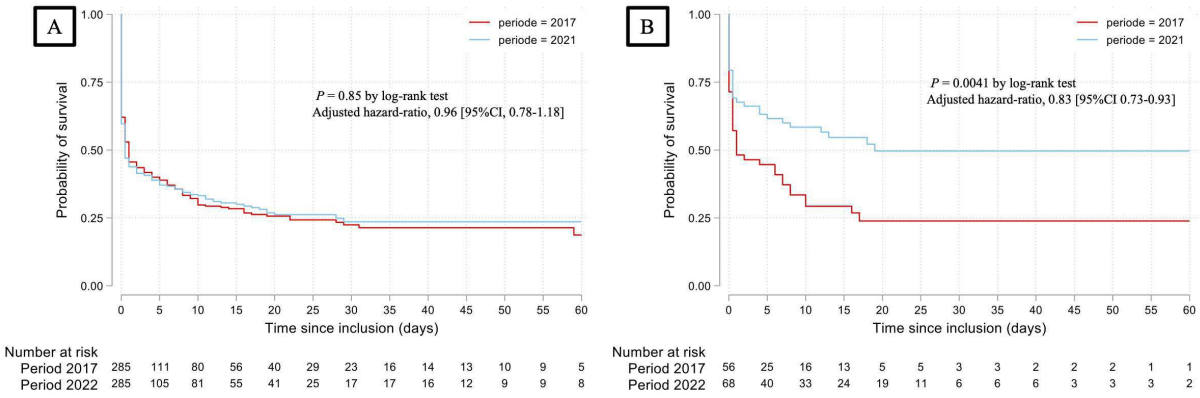


Figure 5. Evolution and cumulated duration of various electrical rhythms. Panel A: All patients in each cohort are represented at each data point on the graph. Upon electrode disconnection, electrical rhythms become unobservable, and patients transition from the last observable rhythm category to the "Electrode disconnection" category. All observable rhythms except “Electrode disconnection” are communicating, i.e., they may be entered and left at any time. Fine ventricular fibrillation is considered a shockable rhythm in this graph, although the recommendations are unclear on this point. Patients with a non-measurable chest compression fraction (no complete cycle) were excluded from this study (no return of spontaneous circulation before ≈ 140 s). Panel B: cumulated duration of various electrical rhythms



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681

682 **Figure 6. Kaplan Meier Survival Estimates.**

683 Panel A: Survival curve for patients according to use of the AWC algorithm (2022) or not

684 (2017).

685 Panel B: Survival curve for patients experiencing cardiac arrest in public places with <12.5

686 minutes between the call and AED switch-on.

687

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1. Supplemental Material & Methods

1.1. AWC algorithm specifics

AWC algorithm has previously been described.[9] For AWC algorithm to be activated, a "standard analysis" must recommend a shock, regardless of its administration to the patient. This recommendation typically occurs during the first rhythm analysis but can result from any subsequent analyses, if the AWC has not been activated beforehand.

Once AWC is activated, it performs analysis in presence of CC during the CPR phase. These analyses are designed not to trigger a "confirmatory analysis" within the first minute of the CPR phase, ensuring a minimum interval for cardiopulmonary resuscitation between two analysis phases.

From the 1st minute after the previous analysis phase, "analysis in the presence of CC" may request to stop chest compressions if the underlying rhythm is analyzed as shockable. "Analysis in presence of CC" characteristics:

- they are performed while CC are being delivered and require 16 seconds of consecutive CC to conclude whether the underlying rhythm is shockable or not;
- if the period of CC delivery lasts less than 16 seconds, the "analysis in presence of CC" is not performed;
- if the period of CC delivery lasts longer than 16 seconds, "analysis in presence of CC" are performed successively, each requiring 16 seconds of CC delivery;

The AWC is deactivated

- when the device is switched off,
- if the electrodes are disconnected,
- if pediatric mode is set
- if another mode is set ("monitor", "manual defibrillation")

1.2. Rhythm annotation methodology and quality management

We used two software to display and annotate the electrical trace:

- A first software (see 1.2.1) to annotate rhythm (Coarse VF, Fine VF, asystole, etc.), to count QRS, P waves, and to tag any noise signal during the analysis.
- A second software (see 1.2.2.)
  - to annotate the rhythm evolution throughout the Observation Windows (ventricular fibrillation / asystole / organized rhythm)
  - to define the presence of a presumed ROSC (see 1.3.)
  - to check for exclusion criteria (pacemaker artifact, ROSC between 1st and 2nd analysis)

1.2.1. Annotation methodology of "standard analysis", "analysis in presence of chest compressions" and "confirmation analysis"

For manual annotations of different types of analysis, we used a dedicated software package: "Detection Survey 04.04". The analyses were displayed one by one, with electrocardiographic traces associated with impedance traces (Figure S2, S3 and S4).

For *standard analysis* and *confirmation analysis*, there were no concomitant chest compressions. The electrocardiographic trace was not disturbed and could be annotated directly.

For *analysis in presence of chest compressions*, several situations were possible:

- chest compressions produced little or no change in electrocardiographic signal: the trace could be read and interpreted directly (Figure S1 panel A; Figure S2)

- chests compressions produced electrocardiographic changes that made direct interpretation impossible. In this case we observed the cardio electric rhythm during the nearest period with no chest compressions (ventilation periods and/or confirmatory analysis periods).
    - If the rhythm was identical before and after the period containing the "*analysis in presence of chest compressions"*, this rhythm was also considered present during "*analysis in presence of chest compressions"* (Figure S1 panel B; Figure S3).
    - If the rhythm was not identical before and after the period containing the "*analysis in presence of chest compressions"*, we dynamically visualized the trace to determine the moment of rhythm change and to assign the adequate rhythm annotation to the analysis in presence of chest compressions (Figure S1 panel C; Figure S4).

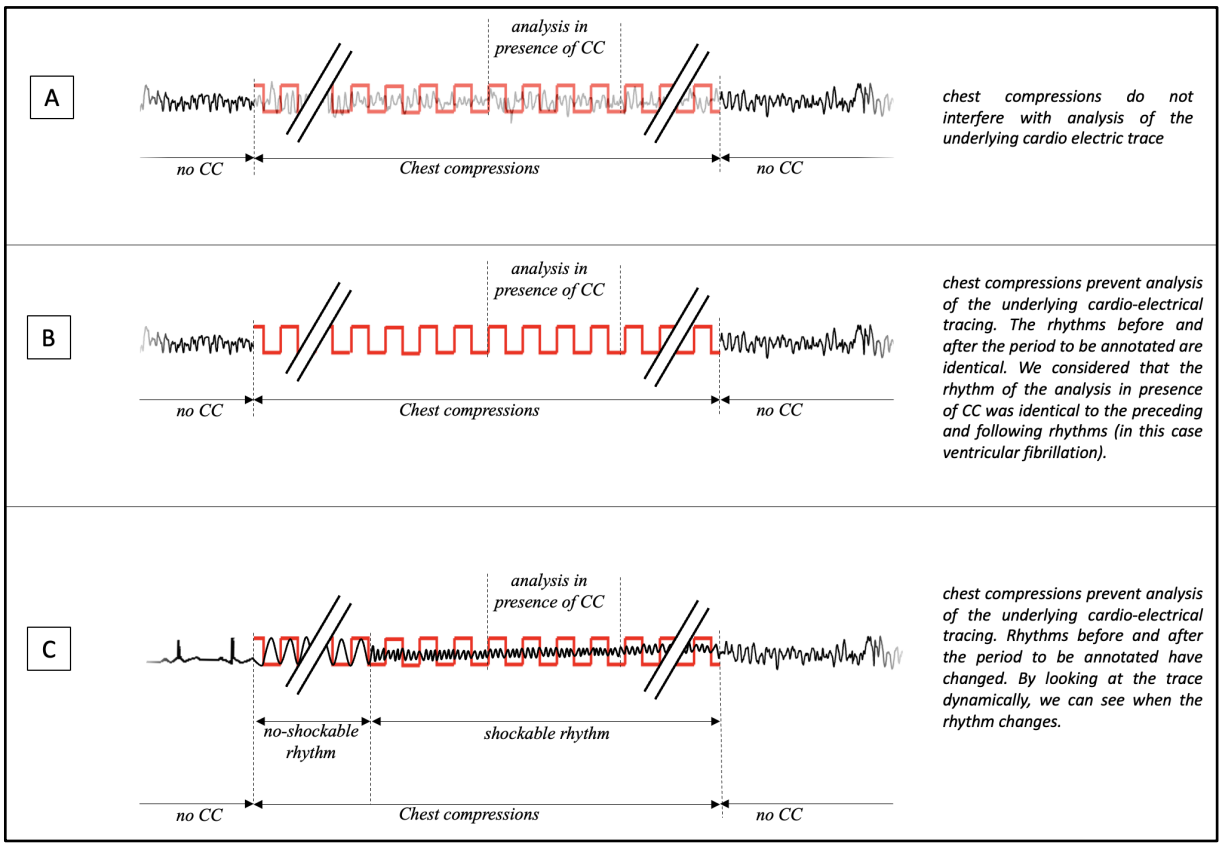


Figure S1: annotation of analysis in presence of chest compressions (CC)

This methodology had already been used in a previous study and had been defined in a written methodology before the study was carried out.[9]

1.2.2. Continuous annotation methodology

For continuous rhythm analysis we used a dedicated Data Management System named SEMA 19.10 software.

- In absence of chest compressions, annotation was direct.
- In presence of chest compressions: we searched for the nearest period without chest compressions and annotated it using the same methodology as described above (see 1.2.1)

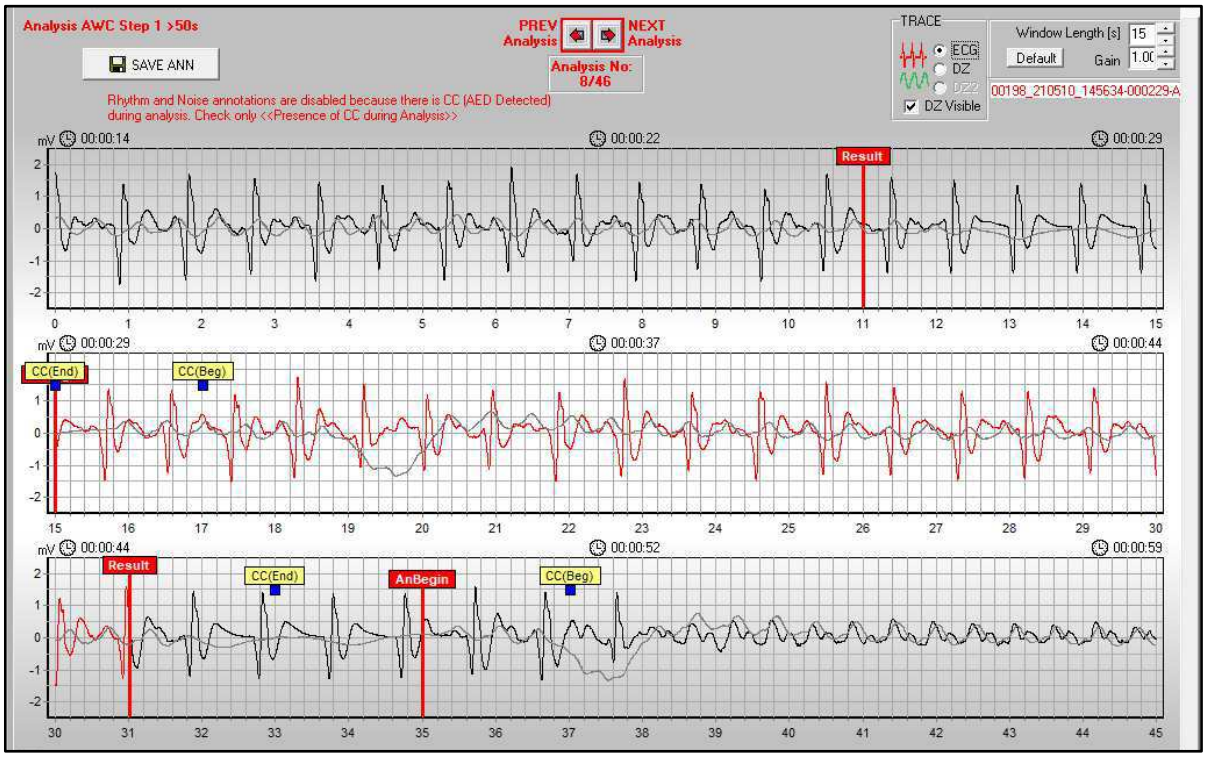


Figure S2: screenshot to illustrate Figure S1 panel A. Chest compressions do not interfere with annotator analysis of the underlying cardio electric trace. Red lines indicate the analysis which must be annotated manually. The CC(Beg) and CC(End) tags are slightly offset in time; here they are not useful as the information on the presence or absence of CC is provided by the impedance curve visible in light grey.

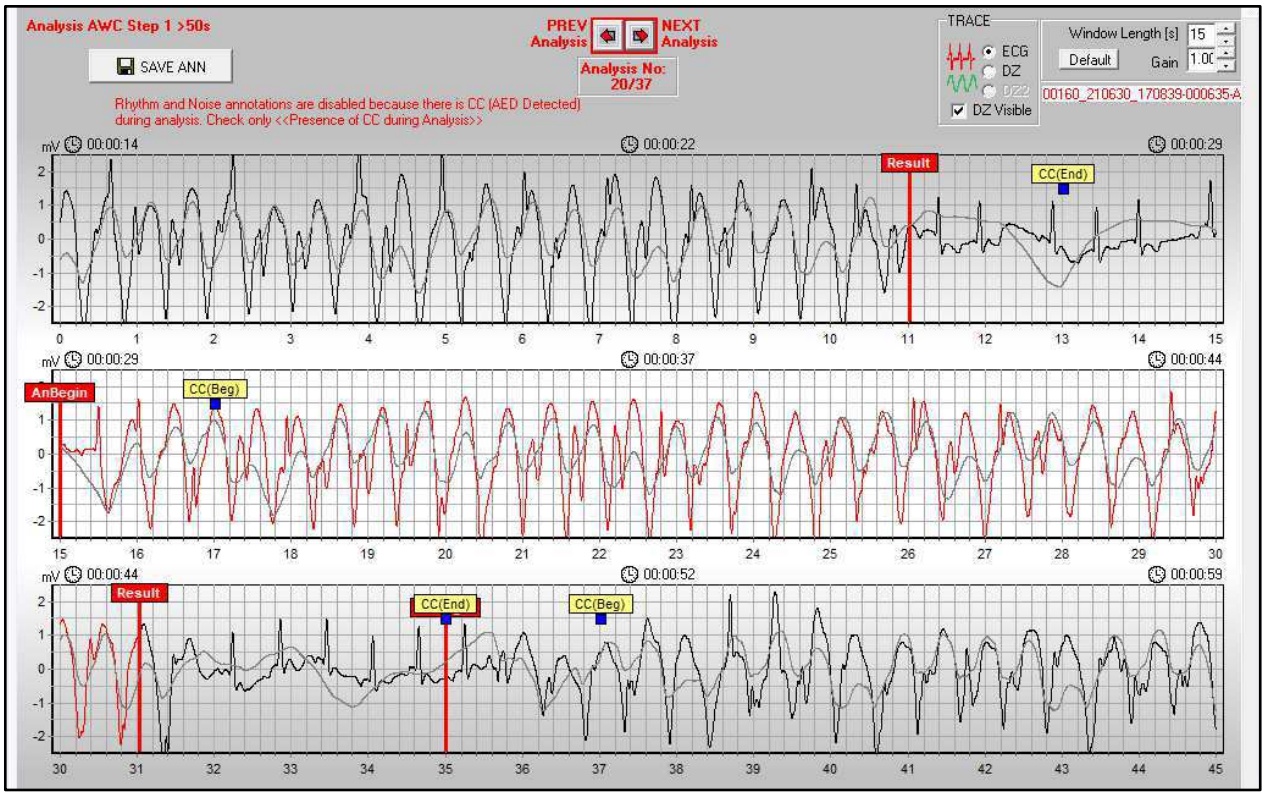
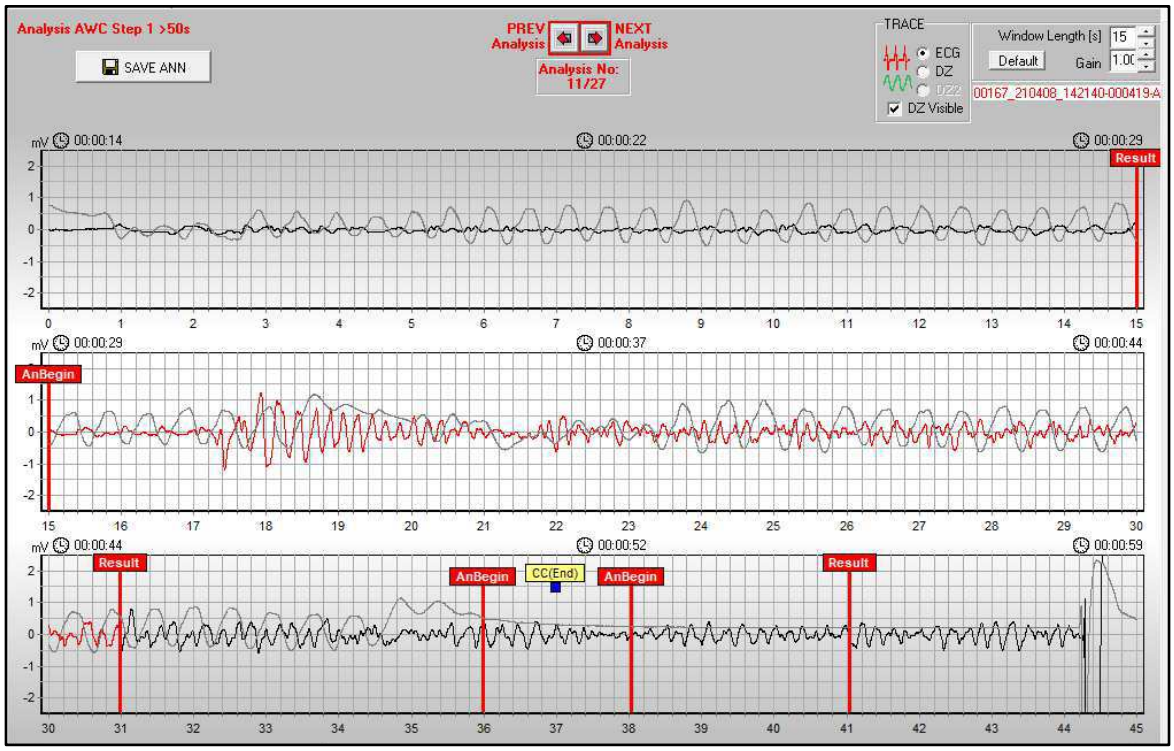


Figure S3: screenshot to illustrate Figure S1 panel B. Chest compressions prevent annotator analysis of the underlying cardiac-electrical tracing. The rhythms before and after the period to be annotated are identical. We considered that the rhythm of the analysis in presence of CC was identical to the preceding and following rhythms (in this case organized rhythm).

Red lines indicate the analysis which must be annotated manually. The CC(Beg) and CC(End) tags are slightly offset in time; here they are not useful as the information on the presence or absence of CC is provided by the impedance curve visible in light grey.



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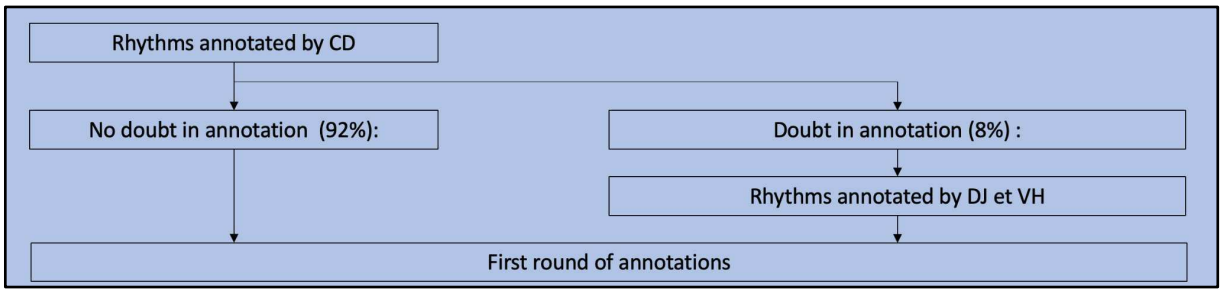
130 *Figure S4: screenshot to illustrate Figure S1 panel C. Chest compressions prevent annotator*
131 *analysis of the underlying cardiac-electrical tracing. Rhythms before and after the period to be*
132 *annotated have changed. By looking at the trace dynamically, we can see when the rhythm*
133 *changes.*

134 *Red lines indicate the analysis which must be annotated manually. The CC(End) tags are*
135 *slightly offset in time; here they are not useful as the information on the presence or absence of*
136 *CC is provided by the impedance curve visible in light gray.*

137

138 ### 1.2.3. Annotation organization



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141 *Figure S5: annotation organization (CD: Clément DERKENNE; DJ: Daniel JOST; VH: Vivien*
142 *HONG TUAN HA)*

143

1.2.4. Annotation quality management

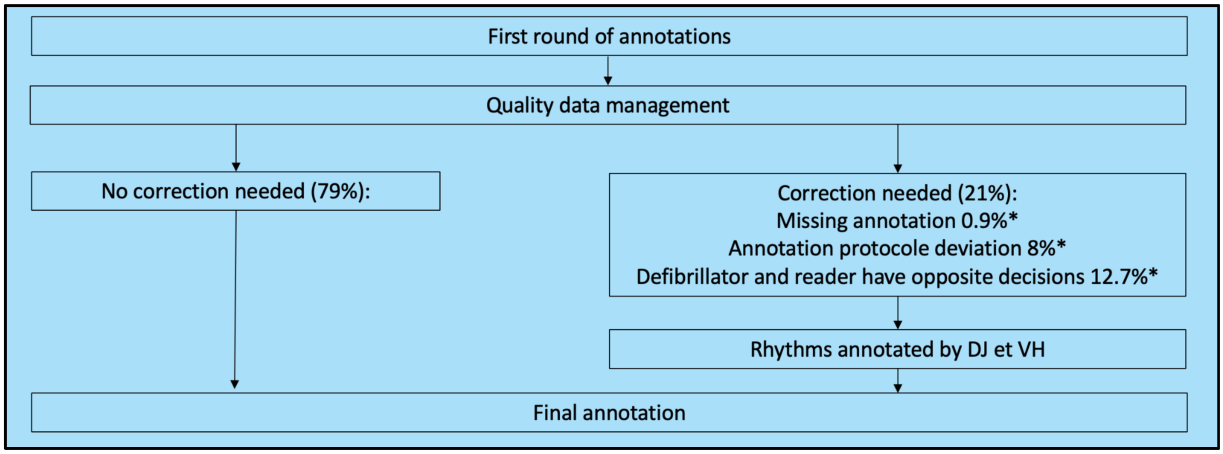


*Figure S6: Data quality management (CD: Clément DERKENNE; DJ: Daniel JOST; VH: Vivien HONG TUAN HA) * some electrical trace may have several reasons for necessary correction*

1.2.5. Inter-annotator agreement

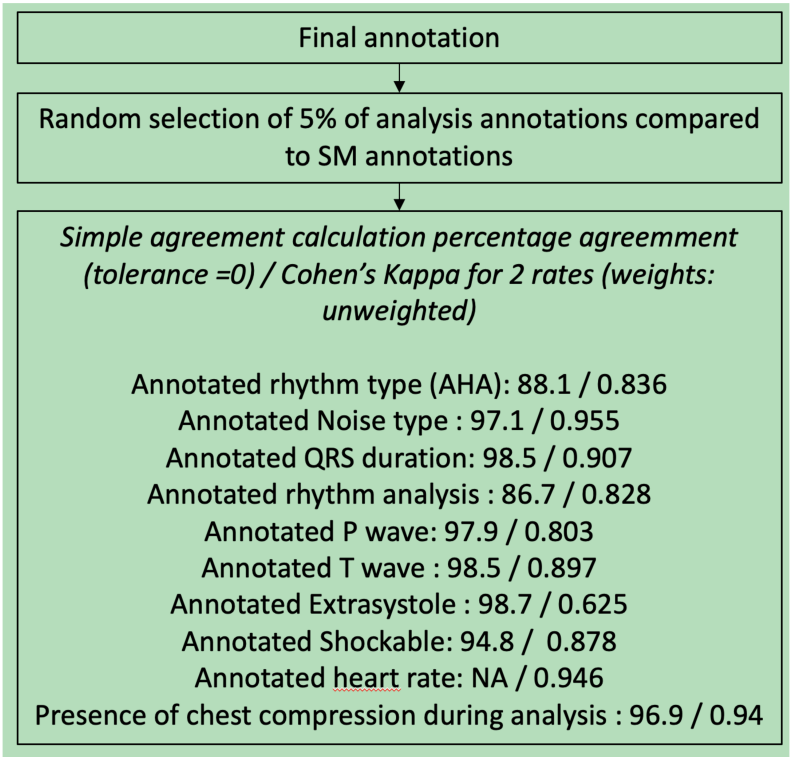


Figure S7: Inter-annotator agreement calculation (SM: Sarah Menetre). NA stands for "Non-Applicable"

1.3. Presumed ROSC illustration

In the METHODS section: *"OW was defined by the time interval from the activation of the defibrillator to the cycle just before the earliest of three events: defibrillator switch off, the 10th minute or a presumed ROSC. The identification of ROSC was formalized by the presence of an organized electrical rhythm, a synchronized variation in thoracic impedance, and the discontinuation of CC, which lasts until the end of the recording".*

For presumed ROSC, three cumulative criteria were required

(1) physiological QRS at a frequency faster than 30/min,

(2) Impedance curve variation that was synchronous with each QRS, indicating cardiac mechanical activity. This notion of impedance curve movement is supported by bibliography. [22, 46, 47]

(3) definitive cessation of chest compressions indicating that the basic life support teams have recognized this ROSC.

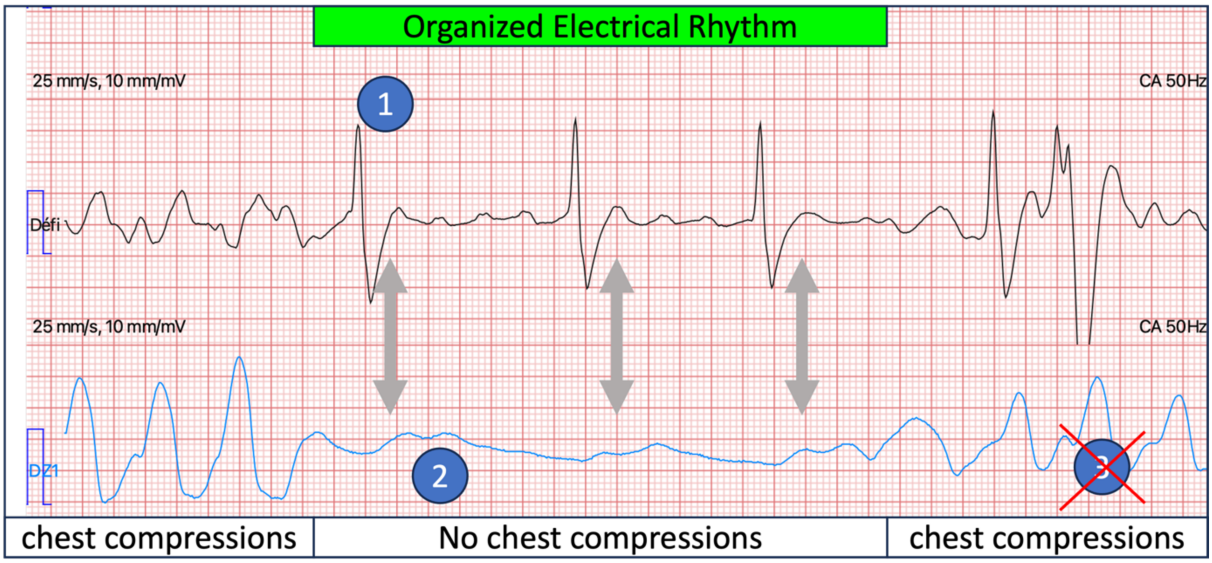


Figure S8: Blue Curve is thoracic impedance trace; black curve is electrocardiographic trace. When chest compressions stop, an electrocardiographic trace appears with organized electrical rhythm (P-QRS-T) (1). Each QRS complex is synchronized with a variation of impedance trace (2). However, there is no definitive cessation of chest compressions. The 3rd criterion is not met, that's why no ROSC were indicated there.

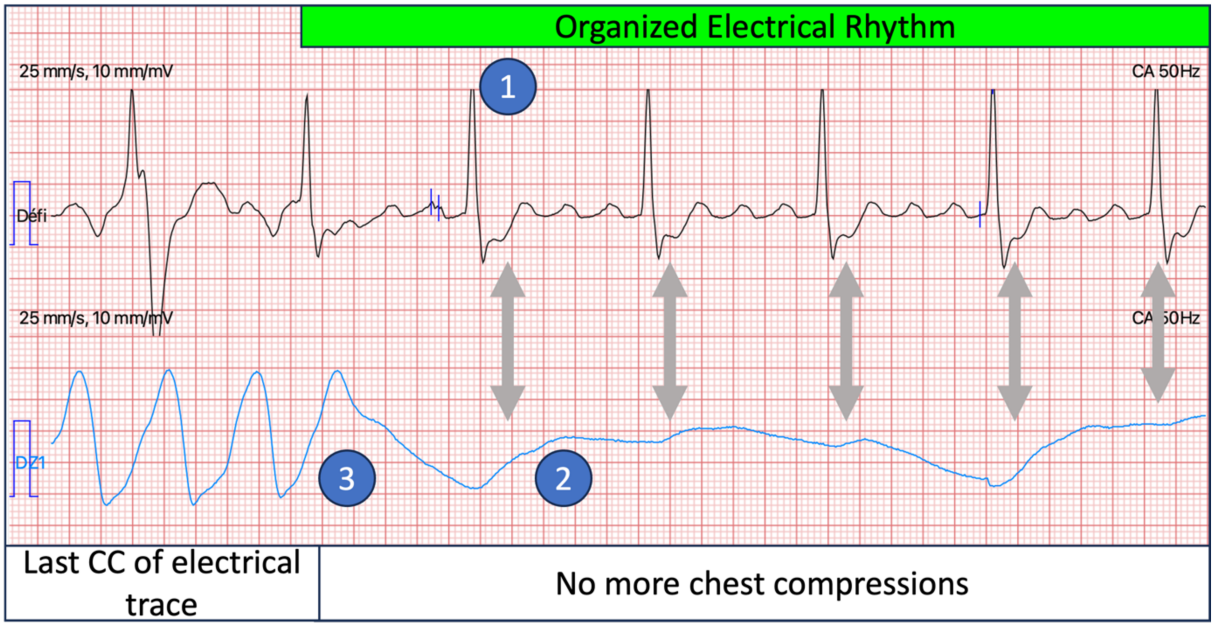


Figure S9: On (3), the last CC of the electrical traces are followed by QRS (1), accompanied by synchronous impedance deflections (2). All three criteria are met and the exact time of the first QRS following the last CC is considered the ROSC timestamp. Lower-frequency impedance variations correspond to spontaneous ventilation or ventilation delivered by rescuers

1.4. Data collection and management

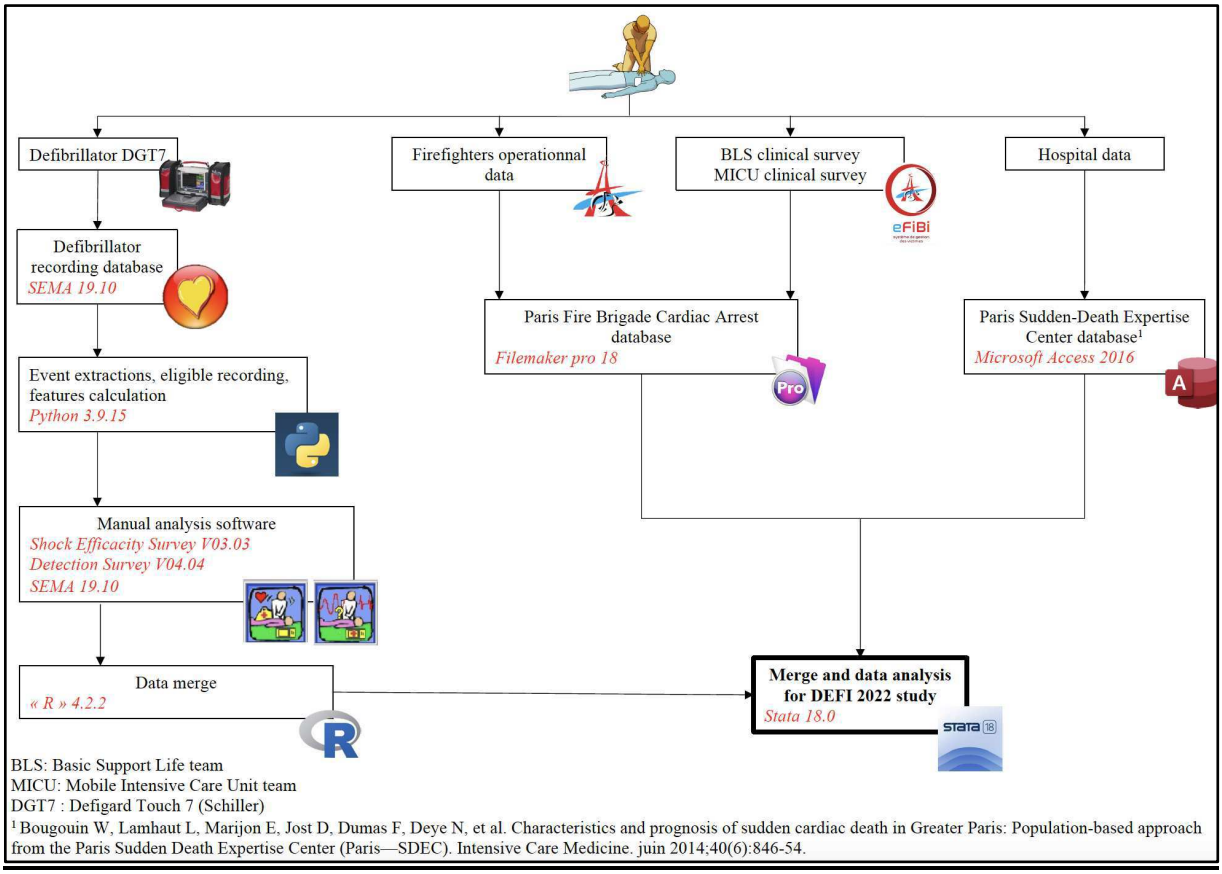


Figure S10: data collection and management

1.5. Statistical consideration

1.5.1. Description of the study cohorts 2017 and 2022

"Patient baseline characteristics and outcomes" and their statistics were performed in agreement with Utstein-style for OHCA.[48]

1.5.2. List of variables

Demographic and Epidemiological Characteristics

Period *(2017 / 2022)*
Date of OHCA

Age *(Years)*
Gender *(Female / Male)*
Bystander Status *(No witness / Witness but no CPR / Witness and early CPR / BLS team-witnessed)*
Location *(Home / Public Place / Other)*
Transfer to hospital with ROSC (beating heart) *(Yes / No)*
Date of discharge from intensive care
Date of hospital discharge
Date of death
Cerebral performance category

Time frames

Time elapsed between first call and AED start-up
First call time to the Dispatch Center

ECG Considerations

Heart rate annotation
P-wave annotation
QRS duration annotation
T-wave annotation
Extrasystole annotation
Noise-type annotation
Annotation of rhythm type
Annotation of rhythm analysis as recommended by AHA (24)
Annotation “presence of refibrillation”
Annotation “refibrillation during cardiac massage”
Pre-shock cardiac rhythm
Post-shock cardiac rhythm at 5, 15, 30, 60, and 120 seconds
Time to recurrence of VF
Ventricular fibrillation storm

The name "ventricular fibrillation storm" is unusual, as it usually refers to "electrical storm". It is more usually applied to patients with ≥3 episodes of VT/VF within 24 hours (each episode at least 5 minutes apart) or VT for >12 hours. These are therefore most often patients with automatic implantable defibrillators or patients monitored in Intensive Care Units. Here, we focus on OHCA patients who do not have a pacemaker/defibrillator (exclusion criterion). We defined the ventricular fibrillation storm of these patients as the duration between the onset of the first recorded ventricular fibrillation and its terminal cessation after the last shock.

AED Characteristics

AED time from start-up to 1st shock
Analysis number
Duration of analysis
Analysis phase
Cycle number
Cycle duration
Number of shocks delivered by AED
Recommended number of shocks by AED

CPR and Resuscitation Quality

Chest compression fraction
Prompt chest compression fraction
Mean cardiac massage frequency
Presence or absence of chest compression
Presence of cardiac massage during AED analysis
Maximum hands-off time
Maximum hands-on time
Hands-off time during the peri-shock phase
Hands-off time during the post-shock phase
Hands-off time during the pre-shock phase
Hands-on ratio during the CPR phase
Hands-on ratio during each cycle

Treatments

Defibrillation
Epinephrine administration

1.5.3. Study design

The study was designed as a pre-post implementation evaluation. The pre-implementation group consisted of OHCA patients managed in 2017 by the Paris Fire Brigade BLS crews with a historical defibrillator algorithm. The post-implementation group consisted of OHCA patients managed in 2022 by the same BLS crews with the AWC defibrillator algorithm. We applied the same eligibility criteria to both groups. Their comparison concerned all the collected variables (epidemiological, electrocardiographic, clinical, and prognostic factors).

We reported categorical variables as frequencies (%) and used Chi_2 or Fisher's exact test, when appropriate, for their comparison. Continuous variables were expressed as medians [InterQuartile Range] and were compared using the Mann–Whitney U test. The effect sizes were represented by the median difference [95% CI; 90 CI for the algorithm diagnostic performance estimators] for continuous variables and the odds ratio [95% CI] for categorical variables. All comparisons used two-sided tests and considered a *P*-value of less than 0.05 to indicate statistical significance.

A comparison of key patient characteristics was performed to validate the comparability of the two groups. This comparison was made for the main variables of interest: age, gender, time response of basic life support teams, and basic life support therapeutics.

We analyzed imputed and non-imputed data. The robustness of the imputed and non-imputed models was evaluated through a sensitivity analysis. We decided to present only the imputed data, given the absence of difference between imputed and non-imputed data.

1.5.4. Primary endpoint assessment

For each patient, Chest Compression Fraction (CCF) was calculated as follow: CCF = Σ (Hands-on 1 duration + Hands-on 2 duration +…+ Hands-on n duration) / Complete cycles duration within the Observation Windows

CCF for each period is reported as median [InterQuartile Range].

A cycle begins with the analysis phase, at the instruction to stop CPR and ends, one or two minutes later, with the instruction to stop CPR for the next analysis.

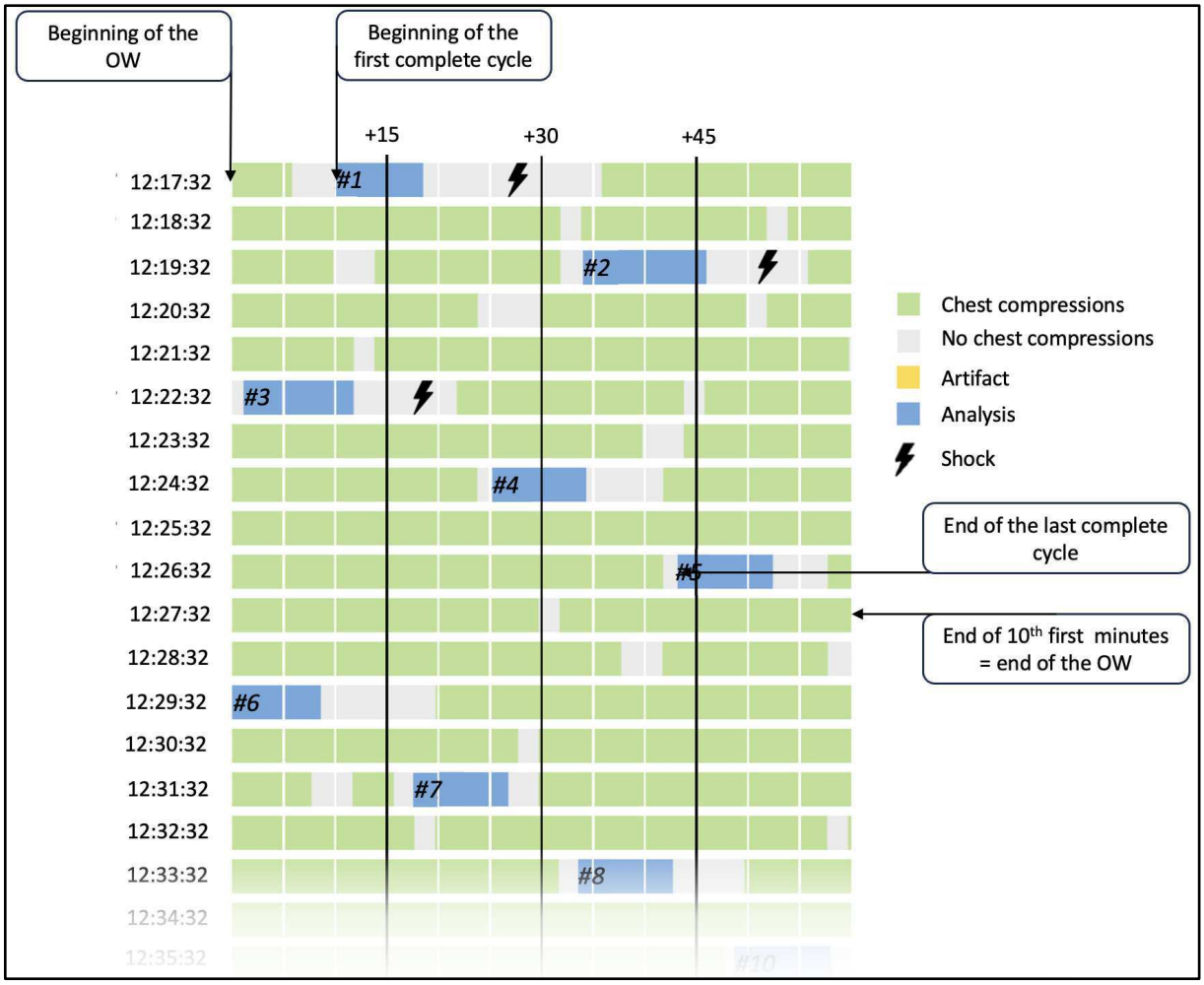


Figure S11: Synthetic view of a patient in cardiac arrest. Chest Compression Fraction is calculated as the sum of the different periods when chest compressions are delivered (green areas) over the duration of the complete cycles within the observation windows. In this case, Windows Observation (WO) is stopped at the 10th min, no electrode disconnection or presumed Return Of Spontaneous Circulation occurs before. This trace is a standard algorithm (2017 cohort): around 10 sec analysis, systematic analysis each 2 min.

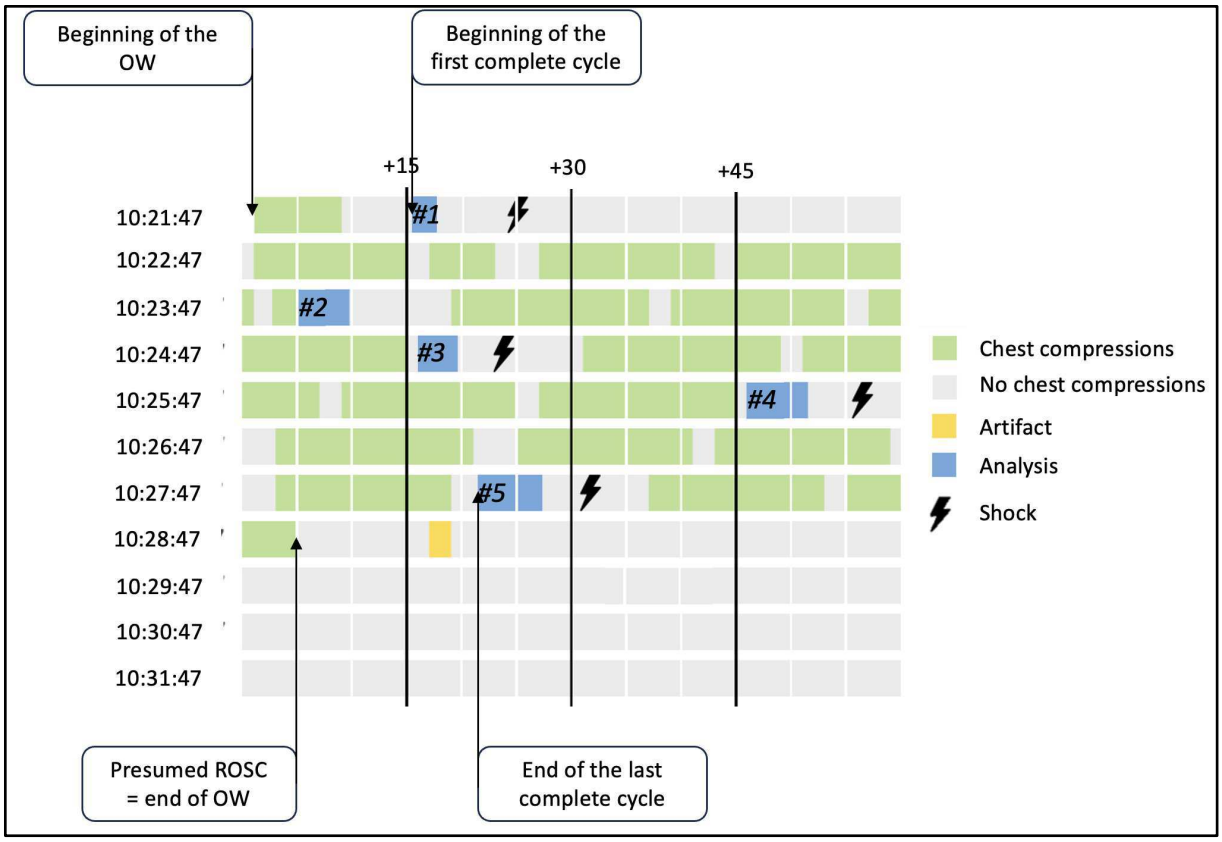
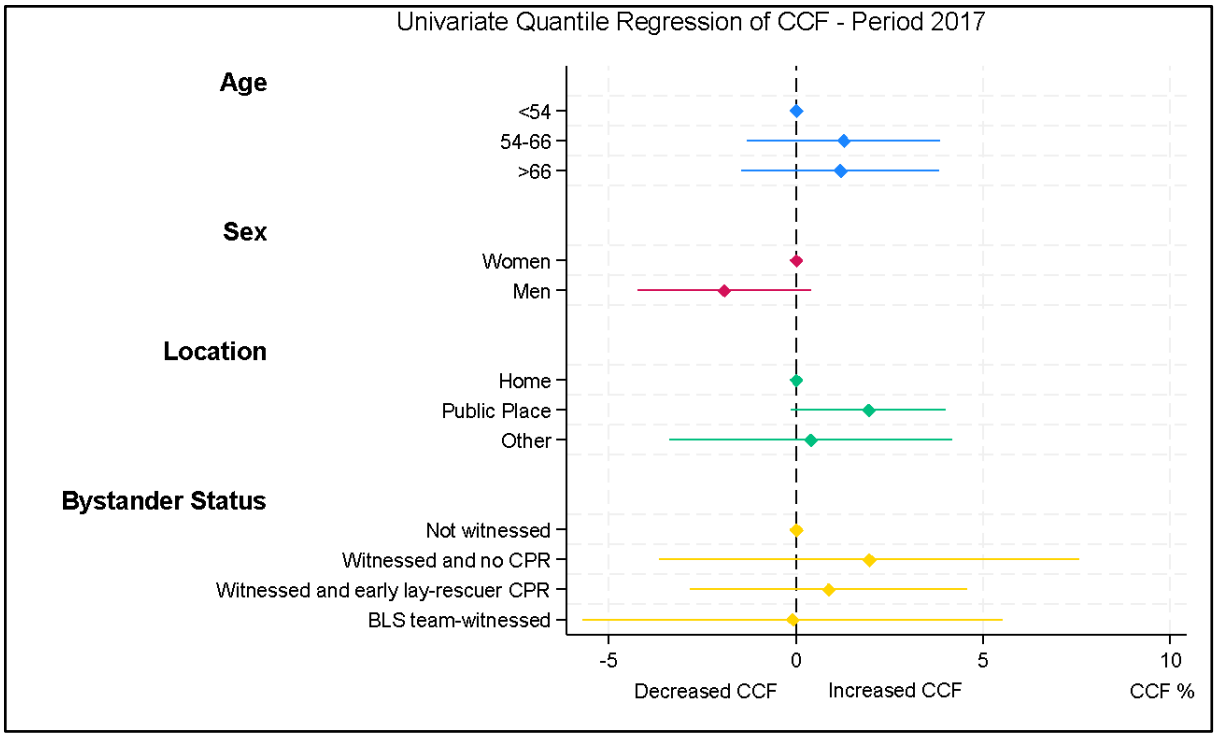
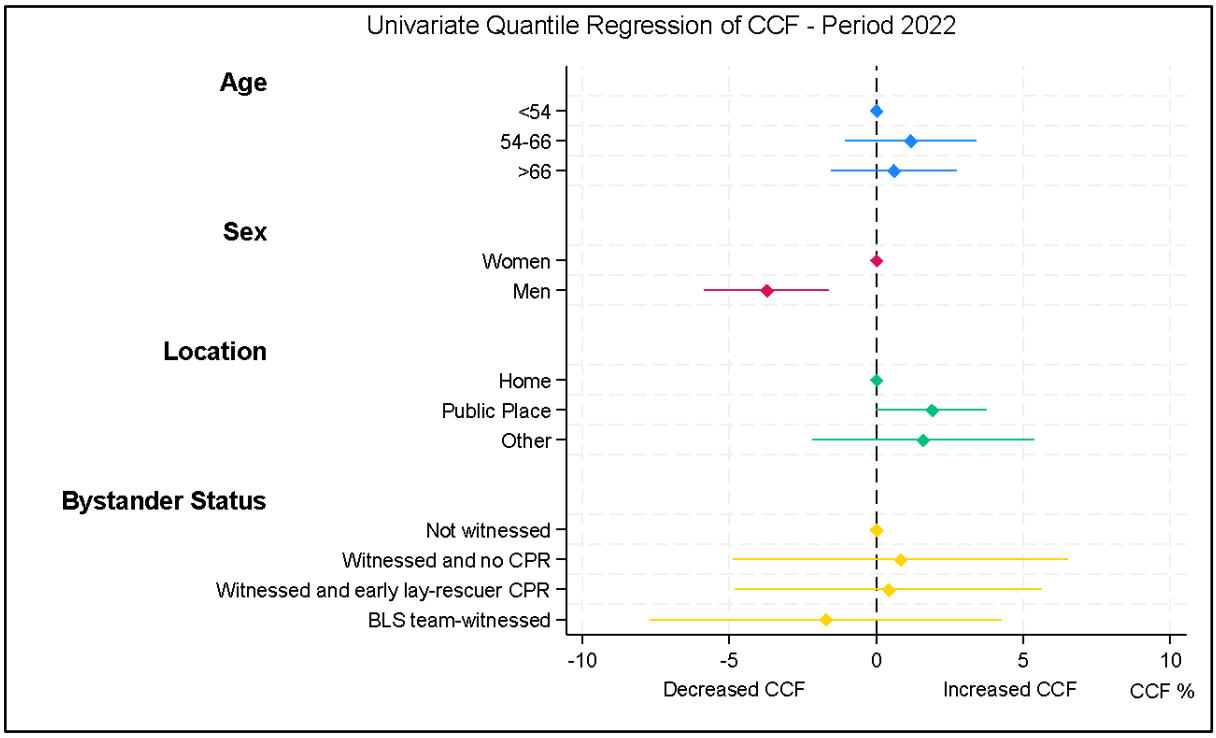


Figure S12: Synthetic view of a patient in cardiac arrest. In this case, Observation Windows (OW) is stopped before the 10th min, because a presumed Return Of Spontaneous Circulation occurs before (Fig S8 and S9). This trace is an AWC algorithm (2022 cohort): around 5 sec analyses, analysis occurs within 1 to 2 minutes of each other.

We planned to conduct our primary outcome analysis using inverse probability weighting to adjust for potential confounding variables. Covariates with strong prognostic significance, referred to as Utstein variables, were included in the multivariate models irrespective of their univariate analysis *P*-values. For the other variables, a *P*-value of less than 0.20 in the univariate analysis qualified them for inclusion in the multivariate model.



Supplemental Figure S13: univariate quantile regression of CC in period 2017



Supplemental Figure S14: univariate quantile regression of CC in period 2022

1.5.5. Secondary endpoint evaluation

Secondary endpoints were estimated using mixed models, where appropriate, to account for time and patient clustering. Survival was estimated with Cox modeling and Kaplan-Meier curve. We used the Log-rank test to compare the curves.

1.5.6. Algorithm performance assessment

We described the performance of both the "analysis during chest compression" (2022) and the "standard analysis (analysis in absence of CC)" (2017). To evaluate the performance based on all manually annotated AED analysis periods, we generated contingency tables taking into account true positives (TP), false positives (FP), true negatives (TN), and false negatives (FN). Performance calculations took into account the patient clustering.

Global performance (Table S3) was calculated as follow for Shockable Rhythm (Coarse VF and Ventricular Tachycardia) :

- Sensitivity = (TP standard analysis + TP confirmation analysis) / (TP standard analysis + FN standard analysis + TP confirmation analysis + FN analysis in presence of CC + FN confirmation analysis)

Global performance was calculated as follow for Non-Shockable Rhythm (Asystolia, Normal Sinusal Rhythm and other Non-Shockable Rhythm):

- Specificity = (TN standard analysis +TN analysis in presence of CC) / (TN Standard analysis + FP Standard analysis + TN analysis in presence of CC + TN confirmation analysis + FP confirmation analysis)

We compared the values obtained with those recommended by the international guidelines.

1.5.7. Preventing bias

A documented procedure was established for expert annotators to avoid annotation bias when reading and analyzing the AED traces. Read tracings considered as challenging to interpret by the first annotator were read twice.

Regarding any possible bias due to modifications in the BLS Teams' behavior, a usability pre-study on mannequins showed that all AWC users performed the expected actions (shock delivery and CPR) without any problems or delay. None of the rescuers was disturbed by the audio prompt modification preceding the analysis (addition of "beeps") or by using the 1-minute protocol. Based on the excellent results of this usability test, we have decided not to train firefighters individually in the AWC algorithm.

Finally, for comparison with the historical cohort, we assumed that the general epidemiology of Paris population in terms of cardiac arrest remained homogeneous, at least between 2017 and 2020-2021, even if it is impossible to grasp the spontaneous evolution of the population. Furthermore, data collection methods and the nature of the collected data remained unchanged between the two periods.

1.5.8. Propensity score and Inverse Probability Weighting.

We calculated the propensity score and performed the inverse probability weighting (IPW) method to mitigate confounding effects and obtain reliable causal estimates of the impact of the two periods on the chest compression fraction (CCF). The covariates, precisely age, sex, location of cardiac arrest, call to AED switch-on time period, and witness status, were selected due to their clinical relevance and potential to introduce confounding bias. We calculated the propensity score using a logistic regression model, where the dependent variable was the period, and the independent variables were the covariates of interest.

We verified the balance of covariates between the two algorithm periods and found an effectively reduced bias across the observed variables.

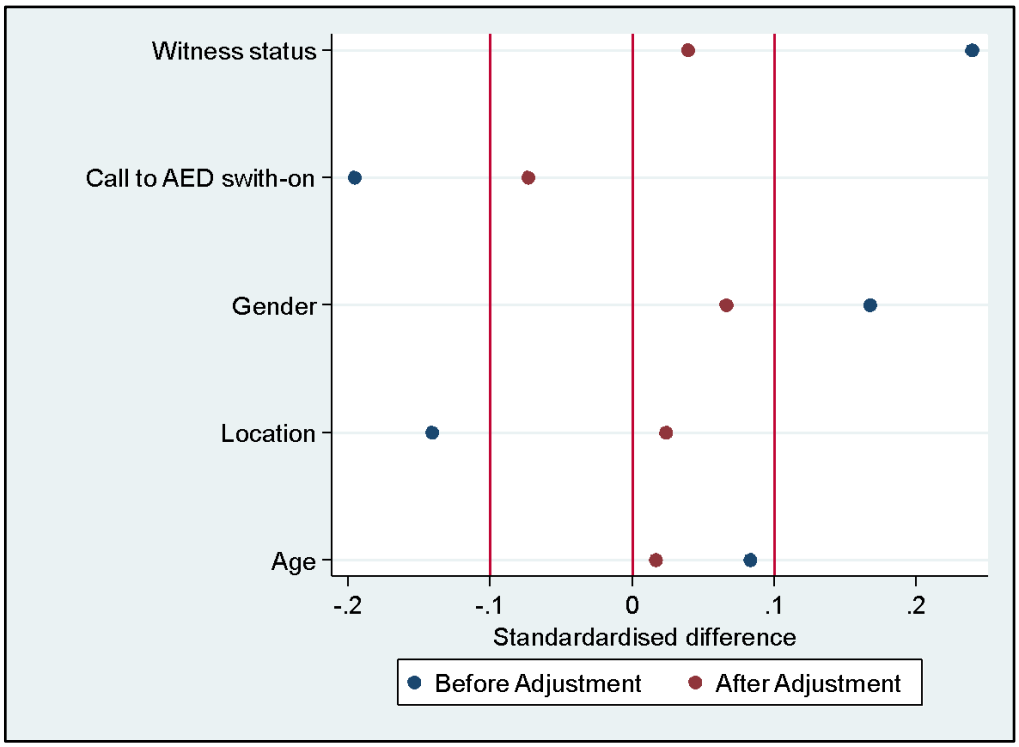


Figure S15: univariate quantile regression of CC in period 2017

1.5.9. Multiple imputation of missing data.

The percentage of missing values ranged from almost 0 for some demographic variables to up to 11.9 % for data on bystander status, and only 89.6 % of the 570 patients in the sample would have been available for analysis. We hypothesized that the missing data were mainly due to the inaccessibility of epidemiological and clinical information. We addressed the problem of missing data using the state-of-the-art technique, including all analysis variables, assuming that missing values were missing at random.[49] Imputed variables were location, sex, age, survival at hospital discharge, epinephrine administration, and bystander status.

We used predictive mean matching with the three nearest neighbors to impute the variables "location," "witness status," "epinephrine administration," and "sex." Linear regression was used to impute the variable age.

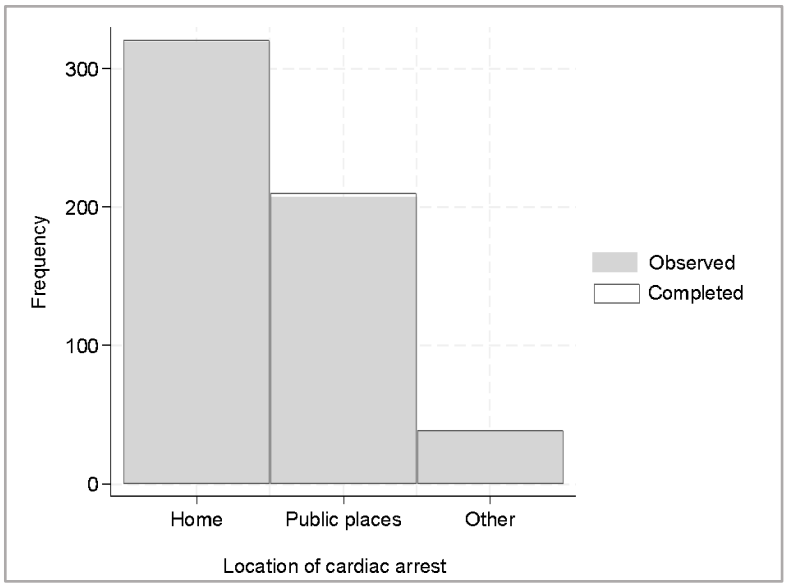
Considering that the estimation of the fraction of missing information was 0.30, Stata 18 mi-impute chained command generated 50 imputed datasets, and visual inspection of imputation convergence led to the choice of 20 burn-in iterations. The analysis run on each dataset were pooled according to Rubin's rules.[50] After having examined the post-imputation diagnostic plots, the imputed values compared reasonably well with the observed values, and the results were similar to multiple imputations, so the imputed results were presented.

	Missing values, N (%)		
	Period 2017	**Period 2022**	**Total**
Location	3 (1.1)	0 (0)	3 (0.5)
Gender	5 (1.8)	1 (0.4)	6 (1.1)
Age	7 (2.5)	9 (3.2)	16 (2.8)
Survival at hospital discharge	7 (2.5)	13 (4.6)	20 (3.5)
Epinephrine administration	14 (4.9)	22 (7.7)	36 (6.3)
Bystander Status	34 (11.9)	25 (8.8)	59 (10.4)

Table S1 Number and percentage of missing data for each imputed variable

Diagnostic plots after multiple imputation

The following plots compare the distributions of the observed (before imputation) and completed (after imputation) values.

403 

404 *Figure S16*

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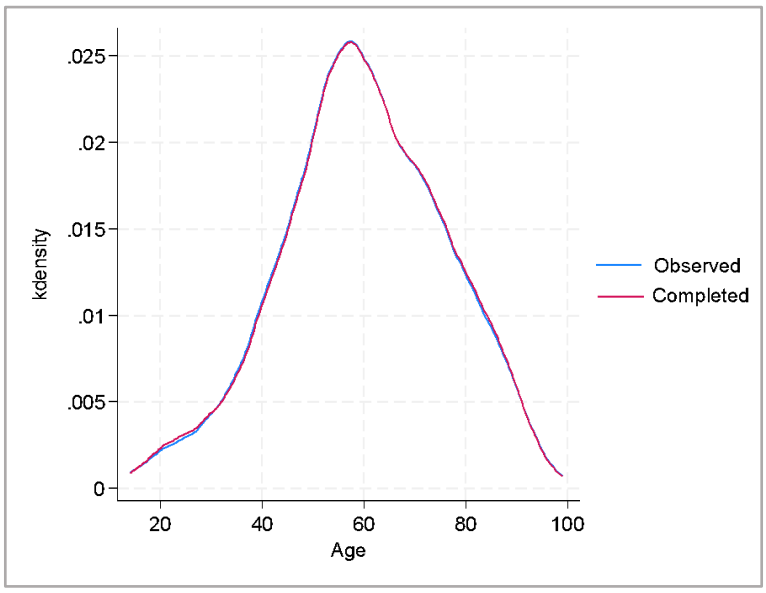
406 

407 *Figure S17*

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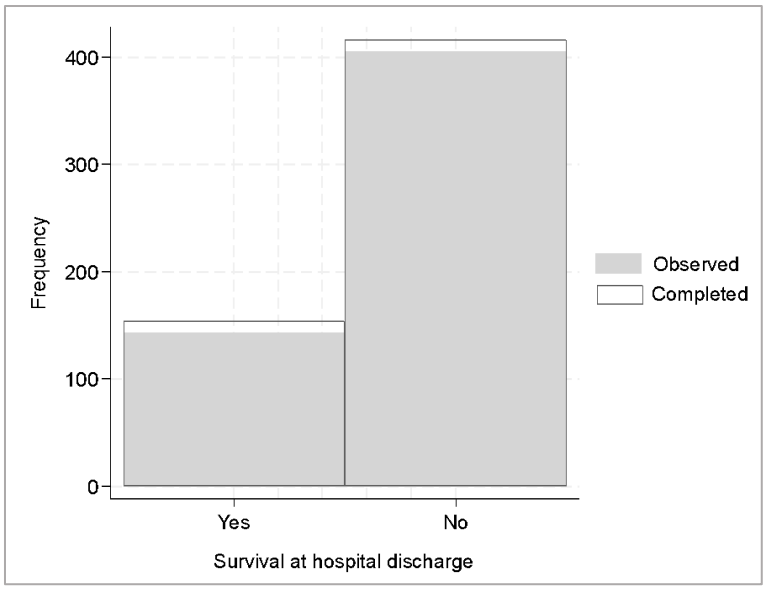
409 

410 *Figure S18*

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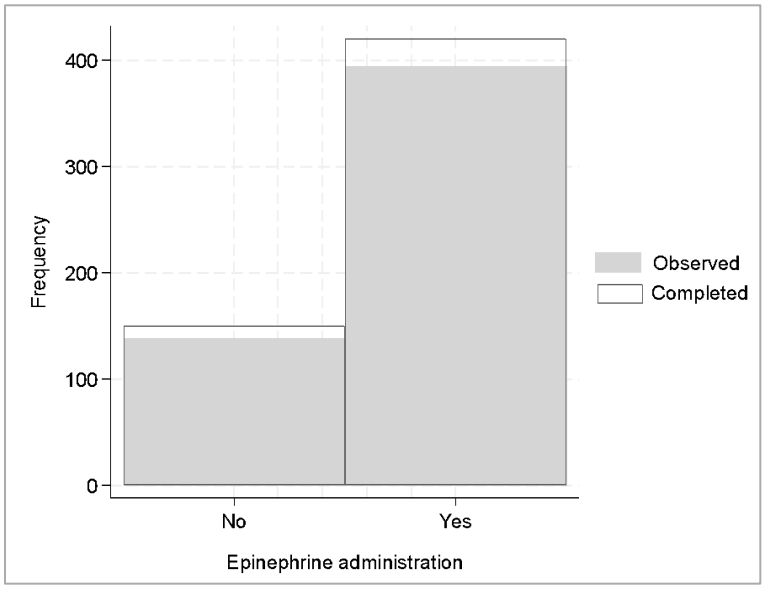
412 

413 *Figure S19*

414

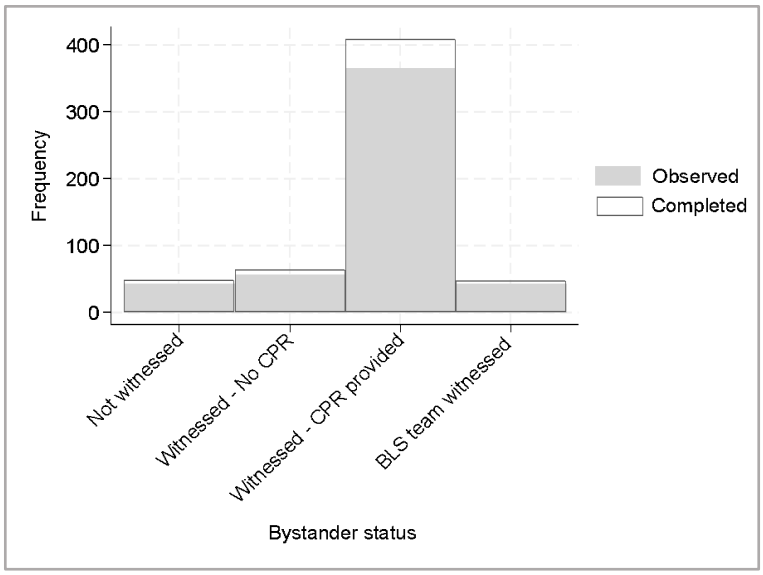

400
300
200
100
0
Frequency
Observed
Completed
Not witnessed
Witnessed - No CPR
Witnessed - CPR provided
BLS team witnessed
Bystander status

Figure S20

418 1.5.10. Description of the excluded patients

	CCF not measurable (no complete cycle) [c] N=16	**Presumed ROSC between 1st shock and 2nd analysis N=12**	**Patients not within the 285th first to be included N= 32**
Cohort			
2017	1	0	0
2022	15	12	32
Men [a]	15 (94%)	11 (92%)	28 (87%)
Age, years, median [IQR]	61 [52-76]	77 [55-81]	59 [55-68]
Location [a]			
Home	9 (56%)	7 (58%)	17 (53%)
Public Place	5 (31%)	4 (33%)	14 (44%)
Other	2 (12%)	1 (8%)	1 (3%)
Bystander status [a]			
Not witnessed	1 (8%)	0	4 (16%)
Witnessed and no CPR	0	0	16 (64%)
Witnessed an early lay-rescuer CPR	8 (62%)	4 (33%)	5 (20%)
BLS team-witnessed	4 (31%)	8 (67%)	0 (0%)
Call to AED connection, min, median [IQR] [b]	16 [12-23]	20 [13-33]	12 [10-16]
AED connection to first shock, s, median [IQR]	21 [18-24]	21 [16-28]	19 [16-24]
Epinephrine administration [a]	9 (90%)	0 (0%)	14 [70%]
Survival at hospital admission [a]	11 (69%)	12 (100%)	22 (69%)
Survival at hospital discharge [a]	3 (23%)	8 (89%)	6 (23%)

[a] N (%); [b] BLS team-witnessed patients are excluded; IQR: InterQuartile Range; [c] usually arrival of the medical team during the first cycle, causing the Basic Life Support team to remove the defibrillator.

419

420 *Table S2 : Description of the excluded patients*

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2. Supplemental Results: VF Detection performances

	Shockable rhythm		Non-shockable rhythm		
	Coarse Ventricular Fibrillation **Sensitivity**	Ventricular Tachycardia > 150/min **Sensitivity**	Asystole **Specificity**	Normal sinusal rhythm **Specificity**	Other non-shockable rhythms **Specificity**
Historical algorithm (2017) [a]	100 [b] *494/494*	- *0/0*	100 [b] *96/96*	100 [b] *8/8*	100 [b] *141/141*
AWC algorithm (2022) [a]	94.9 [93.7 -96.2] *657/692*	71.4 [c] *5/7*	99.7 [99.4-99.9] *617/619*	100 [b] *16/16*	99.3 [99.0-99.5] *1077/1085*
International Electrotechnical Commission and American Heart Association performance goal (24, X)	> 90 *200*	> 75 *50*	> 95 *100*	> 99 *100*	> 95 *30*

Table S3: VF-detection performances

[a] % / *n required,*
[b] due to Sensitivity or Specificity equal to 100%, or the small size of this subgroup no measure of dispersion has been calculated
[c] due to the small size of this subgroup, no measure of dispersion
Results are % [90 Confident Interval] *True positive or negative/total number of cases*;
Intermediate rhythm defined by Kerber et al. (24); fine VF, low VT, and transition rhythm are not shown. Due to analysis with undetermined rhythm, or canceled analysis, or corrupted data, the sum of the detailed rhythms is lower than the amount of analysis in Table 2.

This table shows that more analyses were carried out in 2022 than in 2017. In 2022, analyses were performed closer, but also, each confirmation analysis was preceded by an analysis in the presence of CC.

3. Supplemental Discussion

3.1. Influence of the shorter duration and variable length of cycles on the CCF result

In the discussion part of our manuscript, we suggest two reasons for CCF improvement without being able to determine the respective proportions of each.

The first is a hypothesis based on the performance of the BSL teams and is an instinctive understanding.

The second is a calculator hypothesis. It is based on the fact that the analysis phases do not systematically interrupt the previous CPR phase at the same moment in the cycle in 2017 and 2022: *"more analysis phases occurred during ventilations in 2017 than in 2022 (17% vs. 9%)"*.

To illustrate this point, we propose a caricatural scheme. For the pedagogical purposes of this scheme, we have established CC delivery lasts 16 sec and ventilation delivery lasts 4 sec.

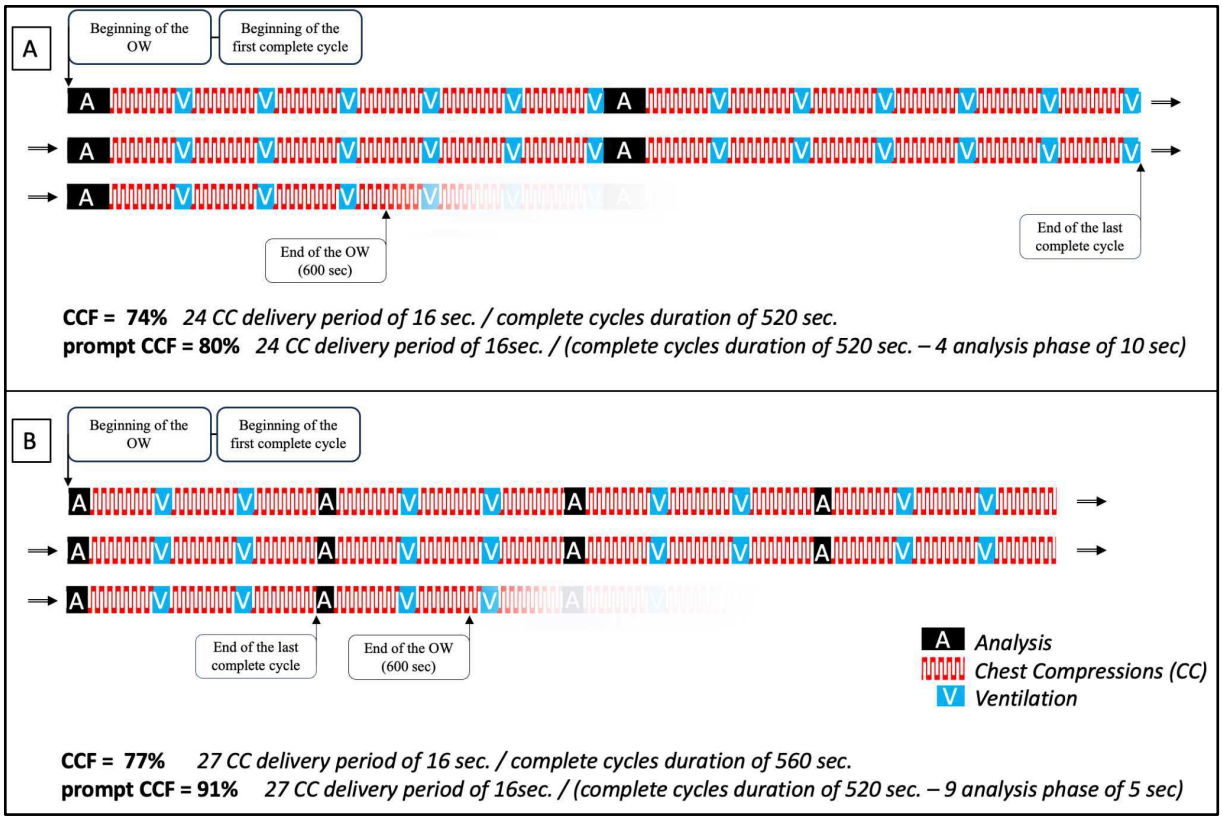

Figure S22: pedagogical and caricatural scheme of influence of cycles duration and moment when analysis phase interrupts previous CPR phase on CCF.

Panel A represents historical algorithm (2017), standard analysis lasts 10 sec and interrupts the previous cycle each time during a ventilation delivery.

Panel B represents AWC algorithm (2022), confirmation analysis lasts 5 secs and interrupts the previous cycle each time during CC delivery.

As this is a pedagogical figure, some choices made here are caricatural and do not correspond to what was actually observed:

- while analysis in 2017 last 10 sec and in 2017 5 sec, we have not shown the entire analysis phase (pre- and post-shock time delay), which varies with each cycle;

- in 2022, we have shown one analysis per minute, whereas the delay varies with each cycle: from a minimum of one min to a maximum of two min;

- analysis phases do not systematically interrupt the previous cycle after ventilation delivery in 2017, and, unlike this scheme, analysis phases do not systematically interrupt the previous cycle during CC delivery in 2022

7.5. Assessment of emergency physicians' performance in identifying shockable rhythm in out-of-hospital cardiac arrest: an observational simulation study.

Assessment of emergency physicians' performance in identifying shockable rhythm in out-of-hospital cardiac arrest: an observational simulation study

Clément Derkenne ,[1] Daniel Jost ,[1] Florian Roquet,[2] Pascal Corpet,[3] Benoit Frattini,[1] Romain Kedzierewicz,[1] Guillaume Bellec,[4] Benjamin Rajon,[5] Marianne Fernandez,[6] Thomas Loeb,[7] Emmanuel Pierantoni,[8] Antoine Lamblin,[9] Bertrand Prunet,[1,10] on behalf of the Paris Fire Brigade Cardiac Arrest Task Force

Handling editor Caroline Leech

► Additional supplemental material is published online only. To view, please visit the journal online (http://dx.doi.org/10.1136/emermed-2021-211417).

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ABSTRACT

Background Emergency physicians can use a manual or an automated defibrillator to provide defibrillation of patients who had out-of-hospital cardiac arrest (OHCA). Performance of emergency physicians in identifying shockable rhythm with a manual defibrillator has been poorly explored whereas that of automated defibrillators is well known (sensitivity 0.91–1.00, specificity 0.96–0.99). We conducted this study to estimate the sensitivity/specificity and speed of shock/no-shock decision-making by prehospital emergency physicians for shockable or non-shockable rhythm, and their preference for manual versus automated defibrillation.

Methods We developed a web application that simulates a manual defibrillator (https://simul-shock.firebaseapp.com/). In 2019, all (262) emergency physicians of six French emergency medical services were invited to participate in a study in which 60 ECG rhythms from real OHCA recordings were successively presented to the physicians for determination of whether they would or would not administer a shock. Time to decision was recorded. Answers were compared with a gold standard (concordant answers of three experts). We report sensitivity for shockable rhythms (decision to shock) and specificity for non-shockable rhythms (decision not to shock). Physicians were also asked whether they preferred manual or automated defibrillation.

Results Among 215 respondents, we were able to analyse results for 190 physicians. 57% of emergency physicians preferred manual defibrillation. Median (IQR) sensitivity for a shock delivery for shockable rhythm was 0.91 (0.81–1.00); median specificity for no-shock delivery for non-shockable rhythms was 0.91 (0.80–0.96). More precisely, sensitivities for shock delivery for ventricular tachycardia (VT) and coarse ventricular fibrillation (VF) were both 1.0 (1.0–1.0); sensitivity for fine VF was 0.6 (0.2–1). Specificity for not shocking a pulseless electrical activity (PEA) was 0.83 (0.72–0.86), and for asystole, specificity was 0.93 (0.86–1). Median speed of decision-making (in seconds) were: VT 2.0 (1.6–2.7), coarse VF 2.1 (1.7–2.9), asystole 2.4 (1.8–3.5), PEA 2.8 (2.0–4.2) and fine VF 2.8 (2.1–4.3).

Conclusions Global sensitivity and specificity were comparable with published automated external defibrillator studies. Shockable rhythms with the best clinical prognoses (VT and coarse VF) were very rapidly recognised with very good sensitivity. The decision-making for fine VF or asystole and PEA was less accurate.

Key messages

What is already known on this subject

- Emergency physicians can use manual or automated external defibrillator (AED) to provide defibrillation of patients who had cardiac arrest.
- Unlike AEDs, the performance of emergency physicians in identifying cardiac arrest rhythms with a manual defibrillator has been poorly explored.
- Knowing their performance on rhythm recognition might guide physicians to a choice of defibrillator.

What this study adds

- We asked emergency physicians to assess 60 rhythms in an online application for whether or not to administer a shock; ventricular tachycardia and coarse ventricular fibrillation were rapidly recognised with very good sensitivity.
- Pulseless electrical activity recognition as a non-shockable rhythm was diagnosed less accurately and would benefit from further training.
- Notably, 57% of emergency physicians preferred to manage cardiac arrest with a manual defibrillator.

INTRODUCTION

Management of cardiac arrest is based on different inter-related and sequential interventions. These actions are described as a *chain of survival*, of which the first links (recognition of cardiac arrest, early chest compressions, early defibrillation) are critical for the patient's survival.[1]

For cardiac arrest with a shockable rhythm (ventricular tachycardia: VT; ventricular fibrillation, coarse or fine: VF), external electric shock delivery may allow a return of spontaneous circulation

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(ROSC). Recognition of shockable rhythms and shock delivery must take place as soon as possible after the patient's collapse. Indeed, the presence of a shockable rhythm decreases rapidly over time and a shorter period of no/low flow is associated with better survival and a neurological prognosis.[2–5]

During cardiac arrest resuscitation, chest compressions induce artefacts on the ECG. Stopping chest compressions is imperative for the analysis of the electrical rhythm by a physician or by the defibrillation algorithm of an automated external defibrillator (AED).[6] Each time the chest compressions are stopped, blood circulation stops, and a dozen new compressions are then necessary to restore effective circulation. The length of the pauses ('hands-off time') is a well-known negative factor for survival.[5 7] Therefore, every electrical rhythm analysis is a trade-off where it is expected that the payoff (shock to a shockable rhythm, then ROSC) will exceed the cost (hands-off time).

Bystander and basic life support teams (BLSt) use an AED for rhythm analysis and shock delivery. However, in France, as in the majority of European countries, emergency physicians (EPs) can use a manual defibrillator.[8] A fairly extensive literature exists on the performance (sensitivity, specificity, speed of recognition) of AEDs, in contrast to the performance of EPs, which has been poorly explored.[9–13]

The objectives of the study were (1) to assess clinician preference for a manual versus an automated defibrillator, (2) to assess their performance (sensitivity/specificity) in correctly identifying shockable rhythm/non-shockable rhythm on defibrillator traces using a simulation model, (3) to identify response times and performance for each rhythm, and (4) to evaluate the association between sensitivity and specificity and the demographic characteristics of the physicians.

METHODS

This is a prospective multicentric study based on computerised simulation.

Inclusion and exclusion criteria

Enrolment took place from September 2019 to December 2019, and involved all the emergency practitioners of six French Emergency Medical Services (EMS) (two from Paris and suburb, two from Alps, one from Marseille and one from La Réunion). Out-of -hospital cardiac arrest (OHCA) in the prehospital setting is managed by EMS teams that include one EP, one nurse and one driver. The EP is always the member of staff who interprets the rhythm and decides whether to shock—there is no joint decision with the team. In these six EMS, there were no specific operational procedures regarding defibrillation or the choice of automated versus manual mode, but European Resuscitation Council (ERC) 2015 recommendations are generally used.

Simulator development

We developed an ECG database from recordings of patients who had OHCA managed by the AED of the BLSt of Paris Fire Brigade. From those recordings, we chose samples of at least 10 s, with a flat impedance curve. This last condition allowed us to avoid ECG artefacts induced by chest compressions or ventilation/gasps of patients.

As this was a simulation study, we did not use the same ratio of the different rhythms (VT, coarse VF, fine VF, asystole, pulseless electrical activity (PEA)) in the database as in real life, due to (1) the scarcity of VT and of coarse VF in real life; (2) the high variability in the morphology of the VT and (3) the absence of variability in the morphology of asystole.[14]

After retrieval and anonymisation, these traces were integrated into a browser-based application. The traces are displayed as they are on a manual defibrillator, progressively, from left to right. Physicians can press, at any time, one of the two buttons: 'shock' and 'no shock'.

For this study, the simulation provided all the traces of the database in random order. The simulation contains 60 traces, and the complete test requires about 10 min. The browser-based application is available online at https://simul-shockfirebaseappcom/. This test was preceded by a questionnaire with demographic questions (age, seniority, manual/AED preference). Incomplete responses were excluded from the analysis. For each trace, the 'shock'/'no shock' response was recorded, as well as the response time.

Definition of a gold standard response

Three experts independently read the traces (DJ has been an EP for 30 years and is an expert at the Sudden Death Expertise Center of Paris; BF has been an EP for 15 years and specialises in the processing of the electrical signal from defibrillators; Pierre Taboulet is an EP and is one of France's leading experts in ECGs). When their shock/no-shock decisions were inconsistent (four cases), the trace was resubmitted to them in an attempt to reach a consensus. When disagreement persisted, the trace was removed from the database (two cases). Their concordant answers constituted the gold standard for defining shockable rhythm/non-shockable rhythm. The experts answered on the same simulator that was used to test the included physicians, in accordance with 2015 ERC recommendations, and within 20 s by trace.[7] The gold standard, therefore, incorporates dynamic reading of the traces but also the imprecision of measurement of the electrical signal and analysis on a screen without a gridded background.

Statistics

Three different shockable rhythm types (VT, fine VF, coarse VF) and two different non-shockable rhythm types (PEA, asystole) exist. We cannot give sensitivity for non shockable rhythms since our definition of sensitivity concerns only shockable rhythms or specificity for shockable rhythms since our definition of specificity concerns only non shockable rhythms. For each physician and each different shockable rhythm, we determined sensitivity:

Table 1 Demographic data of emergency physicians (n=190)

Age (years, median (IQR))	36 (32–44)
Gender male	122 (64%)
Experience as an emergency physician (ED and/or prehospital Emergency Medical Service) (years, median (IQR))	7 (3–13)
Number of patients who had cardiac arrest managed per year	
0–5	31 (16%)
6–10	69 (36%)
11–20	51 (27%)
>20	39 (20%)
Prefer to manage patients who had cardiac arrest with	
Automated defibrillator	66 (35%)
Manual defibrillator	108 (57%)
No preference	16 (8%)

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$$\left(\text{sensitivity} = \frac{\text{shockable rhythm with shock decided}}{\text{shockable rhythm with shock decided} + \text{shockable rhythm with no shock decided}}\right).$$

For each physician and each non-shockable rhythm, we determined specificity:

$$\left(\text{specificity} = \frac{\text{non}-\text{shockable rhythm with no shock decided}}{\text{non}-\text{shockable rhythm with no shock decided} + \text{non}-\text{shockable rhythm with shock decided}}\right)$$

Since, in the simulation, the five types of rhythms were not present in the same proportions as in real life, for each doctor the global sensitivity was calculated as the weighted average of the three shockable rhythm subgroups and the global specificity as the weighted average of the two non-shockable rhythm subgroups. For the weighting, Paris Fire Brigade unpublished 2017 real proportions were used (shockable rhythm: coarse VF 6.5%, fine VF 2.1%, VT 0.4%; non-shockable rhythm: asystole 62.0% and PEA 29.0%).

The strategy of weighting sensitivity/specificity values by their real weights inflated the theoretical number of proposed traces. This resulted in an unbiased estimate of the intrinsic qualities of the test but an artificial decrease in its variance. However, at no time were the variances of the sensitivities and specificities of any of the physicians in the sample used. An estimation of a receiver operating characteristic (ROC) curve was plotted by local polynomial regression from each calculated EP sensitivity /(1–specificity) to estimate the performance of the physicians as one would the performance of an index test and against a reference standard in a diagnostic study. The associated area under the curve (AUC) was estimated by trapezoidal method. Continuous variables were summarised using median (IQR) or mean (SD) and compared using the Wilcoxon rank-sum test or a one-way analysis of variance where appropriate. Association parameters between sensitivity or specificity and physician demographic parameters were estimated by linear regression model. Categorical variables were summarised using frequencies with their percentages and compared using Fisher's exact test. Where appropriate, the normality of the data distribution was assessed graphically by the histogram method. All statistical tests were two tailed, with p values of <0.05 considered significant.

Regulatory considerations

The data collection and processing were carried out in strict compliance with French regulations (CNIL MR003).

Patient and public involvement

Patient and public involvement are not appropriate for our study.

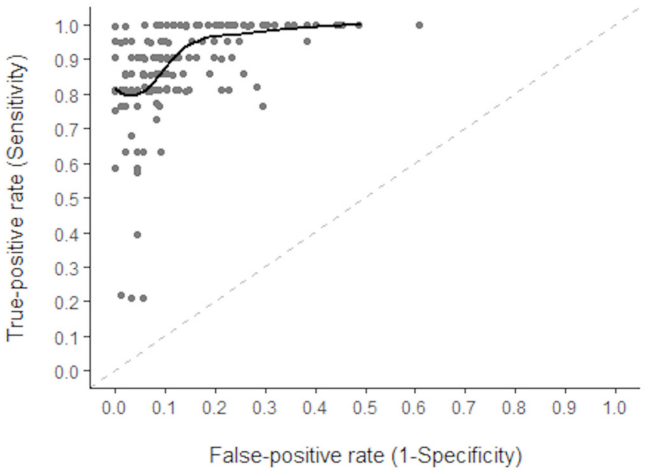

Figure 1 Receiver operating characteristic curve.

RESULTS

Two hundred sixty-two physicians were invited to participate, and 215 responded (see online supplemental table). We excluded 25 incomplete responses and finally analysed 190 responses of 60 traces for 11 400 tests. Of those included, 63% were male, with a median age of 36 (32–44) years, and 7 (3–13) years of experience in emergency medicine. More than half (57%) preferred to manage cardiac arrests with a manual defibrillator (table 1).

The simulation included 14 tracings with asystole, 29 PEA, 4 coarse VF, 5 fine VF and 8 VT. By weighting each of the shockable rhythm/non-shockable rhythm to real-life ratios, global sensitivity for shock delivery for shockable rhythm was calculated as 0.91 (IQR 0.81–1.00), and global specificity for no-shock delivery for non-shockable rhythm was 0.91 (0.80–0.96). The positive predictive value (probability that a shock delivered to a shockable rhythm) was 0.99 (0.98–1.00); the negative predictive value (probability that a no-shock decision was made on a non-shockable rhythm) was 0.48 (0.33–0.66). More precisely, sensitivity for shock delivery for VT or coarse VF was 1.0 (1.0–1.0); specificity for no-shock delivery for asystole was 0.93 (0.86–1) (table 2). The estimated ROC curve associated with the performance distribution of the 190 physicians included is shown in figure 1. The AUC obtained by the trapezoidal method is estimated at 0.97. Median response times (in seconds) differed between rhythm types, but all medians are below 3 s (all $p<0.005$; figure 2).

There is a statistical association between physician sensitivity and no preference between the use of manual and automated defibrillators (OR=0.93; 95%CI 0.86 to 0.99; p=0.03) and

Table 2 Performance of emergency practitioners (median (IQR))

	Sensitivity	Specificity	Performance goal, according to Kerber *et al*[13]
Coarse ventricular fibrillation	1.0 (1.0–1.0)	*	*>0.90*
Fine ventricular fibrillation	0.6 (0.2–1.0)	*	*Report only*
Ventricular tachycardia	1.0 (1.0–1.0)	*	*>0.75*
All shockable rhythms†	0.91 (0.81–1.00)	*	
Pulseless electrical activity	*	0.83 (0.72 to 0.86)	*>0.95*
Asystole	*	0.93 (0.86 to 1.00)	
All non-shockable rhythms†	*	0.91 (0.80 to 0.96)	*>0.95*

*We cannot give sensitivity for non-shockable rhythms, since the mathematical definition of sensitivity concerns only shockable rhythms and vice versa.
†By weighting each of the shockable rhythm/non-shockable rhythm to real-life ratios, we were able to calculate global sensitivity and specificity.

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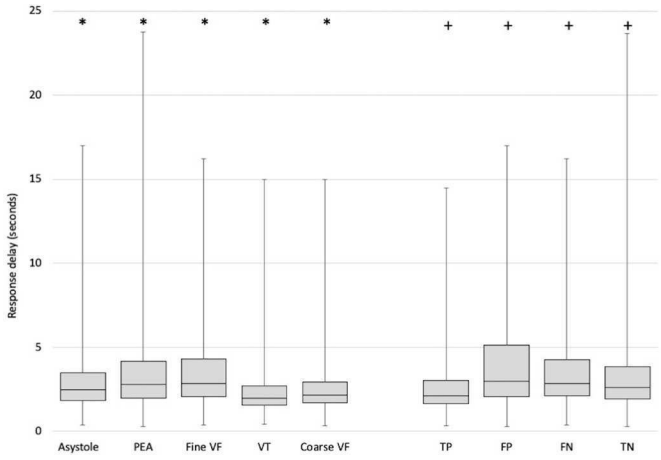

Figure 2 Response delay according to the type of recording. + and *p<0.005. FN, false negative (shockable rhythm with no shock delivered); FP, false positive (non-shockable rhythm with shock delivered); PEA, pulseless electrical activity; TN, true negative (non-shockable rhythm with no shock delivered); TP, true positive (shockable rhythm with shock delivered); VF, ventricular fibrillation; VT, ventricular tachycardia.

between specificity and male gender (OR=1.04; 95% CI 1.00 to 1.07; p=0.03) (table 3).

DISCUSSION

In this study, we found that among 190 EPs representing six regions in France, sensitivity and specificity for detecting any shockable rhythm were high (0.91 (0.81–1.00) and 0.91 (0.80–0.96), respectively). However, the sensitivity for fine VF was insufficient, and the specificity for PEA was also suboptimal.

In the literature, there are very limited data on the sensitivity/specificity of manual defibrillation: Cheskes *et al* reported a sensitivity/specificity of 1.0/0.99 in basic and ALS teams[15] ; Kramer-Johansen *et al* reported up to 26% inappropriate shocks[16] and Pytte *et al*, in a simulation study, found a sensitivity/specificity of 1.0/0.89.[17] For automated defibrillation, in contrast, studies show sensitivity/specificity: 0.91–1.00/0.96–0.99,[11] 0.84/0.96,[10] and 0.97–1.0/0.97–1.0.[12] The overall sensitivity/specificity of the physicians included in our simulation is therefore essentially identical to those found with AEDs and other manual defibrillation studies. These performances can also be compared with the guidelines (dating from 1997 and concerning AEDs): the sensitivity measured is above the recommended 0.90, and the specificity is below the recommended 0.95–0.99.[13] To the best of our knowledge, our work is the only one specifically addressing each of the cardiac arrest rhythms (VT, coarse and fine VF, PEA and asystole).

While globally, EPs had high sensitivity and specificity, this varied by rhythm. We measured a very high sensitivity for the shockable rhythms with the best clinical outcome (VT and coarse VF). For VT, our sensitivity was 1 (1–1), while prior literature suggests that AEDs are least sensitive for these rhythms (0.36–0.96 for different AEDs in the literature).[9 18] For coarse VF, our sensitivity was similar to that of the AEDs (12). For these two rhythms, the response time of physicians was very fast: 1.6 s for VT and 2.1 s for coarse VF, whereas the most modern AED algorithms need 3–5 s to analyse a shockable rhythm.[19 20]

However, the sensitivity for fine VF was insufficient and the specificity for asystole was insufficient. We believe that the difficulty in precisely measuring the amplitude of the electrical signal complicates the distinction between asystole and fine VF. This challenge, in our simulator as in real life, may be related to the absence of a gridded background and the dynamic aspect of the continuous presentation on a defibrillator screen. There is, moreover, a *continuum* between asystole and fine VF which makes the distinction very delicate. The ERC 2015 guidelines even specifically recommend, in case of doubt between extremely fine VF and asystole, that no shock be administered and that chest compressions be resumed.[7] The 2015 ERC recommendations do not specify which amplitude is 'extremely fine VF' and therefore leave room for discretion which was, in our work, the concordant answer of the three experts.

We were surprised by the poor specificity for PEA. Excessive shock delivery can cause myocardial damage and increase hands-off time, and may induce a shift from an organised electrical rhythm to asystole or shockable rhythm.[16 21] The correct identification of PEA as non-shockable rhythm is an important area for improvement for EPs. There may be here an element where physicians choose to shock for fear of missing the most likely life-saving procedure: this warrants further investigation.

The ROC curve illustrates the distribution of physician performance. Although two demographic factors were statistically associated with sensitivity or specificity, their ORs were low, with unclear clinical significance. We did not identify a profile of EPs with better sensitivity or specificity than the rest of the

Table 3 Association between sensitivity, specificity and demographic data of emergency practitioners

	Sensitivity		Specificity	
	OR (95% CI)	P value	OR (95% CI)	P value
Age (years)	0.99 (0.99 to 1.00)	0.38	1.0 (0.99 to 1.00)	0.32
Gender male (ref: female)	1.02 (0.98 to 1.06)	0.44	1.04 (1.00 to 1.07)	0.03
Experience as an emergency practitioner (years)	1.0 (0.99 to 1.00)	0.97	0.99 (0.99 to 1.00)	0.24
Number of patients who had cardiac arrest managed per year				
0–5	1	–	1	–
6–10	1.02 (0.96 to 1.08)	0.58	0.96 (0.91 to 1.00)	0.05
11–20	1.04 (0.98 to 1.11)	0.21	0.96 (0.91 to 1.00)	0.05
>20	1.02 (0.95 to 1.08)	0.78	1.00 (0.95 to 1.05)	0.99
Prefer to manage OHCA with a defibrillator				
Manual	1	–	1	–
Automated	0.99 (0.96 to 1.04)	0.95	0.99 (0.97 to 1.03)	0.96
No preference	0.93 (0.86 to 0.99)	0.03	1.03 (0.97 to 1.09)	0.32

OHCA, out-of-hospital cardiac arrest.

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included population: in particular, experience does not appear to be associated with better sensitivity or specificity. A tool such as our simulator can allow EPs to train to progress, easily measure their performance, and, maybe, choose in full awareness between manual defibrillation or defibrillation by an AED. The *Simulshock* simulator is freely available online, with correction at the end of the test. This simulator is complementary to other tools such as monitoring performance in time-appropriate simulations with a manikin or retrospectively assessing real-life prehospital data. As an advantage, the use of simulation is risk-free for patients and blame-free for doctors and has already shown performance improvement compared with didactic instructions.[22 23]

Although we could not directly compare the performance of EPs with that of AEDs on the same rhythms, and knowing all the biases specific to simulation work, this work offers a very indirect comparison of the performance of manual and AED defibrillation. To maximise a patient's probability of survival, it is important to know whether manual or automated defibrillation is more sensitive, specific and fast. In the literature, the primacy of one of these three parameters in survival has not been determined. While physicians appear to be faster and more sensitive than AEDs for VT, they are faster but less sensitive and specific for fine VF/PEA. No defibrillation strategy has yet been proven to be superior.[5 7 24]

There are limits to our work and extrapolating the results of this study to real life is not so straightforward. In real life, some parameters might influence the choices of physicians for manual defibrillation, especially when it is necessary to distinguish between asystole and fine VF. These parameters could be, for example, decisions made by an AED used before the physician's arrival, or criteria for good/poor patient prognosis, or an increase in end-tidal CO_2. Another limitation is the use in this study of artefact-free ECGs, which do not always exist in real-life analyses (which include patient gasps, etc).[25] It should also be noted that requiring the EPs to make choices about 60 consecutive traces in 10 min is a possible source of bias in the study. This may have tired the EPs or helped them respond more quickly as they gained experience on the simulator.

CONCLUSIONS

Sensitivity and specificity of EPs for shockable rhythms in this study were comparable with published AED studies. Shockable rhythms with the best clinical prognoses (VT and coarse VF) were rapidly recognised with very good sensitivity. The decision-making to shock fine VF, or not shock asystole and PEA was less accurate and should be considered when making decisions about the use of AED versus manual defibrillators.

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	Paris Fire Brigade	SAMU Haut de Seine	Marseille Naval Fire Battalion	SAMU Hautes-Alpes	SAMU St Pierre Réunion	SAMU Saint-Jean de Maurienne	Total
Emergency practitioners invited to the simulation	93	55	35	32	34	13	262 (100%)
Emergency practitioners' responses	85	31	30	29	29	11	215 (82.0%)
Emergency practitioners' complete answers: included	77	20	28	26	28	11	190 (72.5%)