Public Access Defibrillators in Scotland

Reviewing the Current State and Keys to Improving the Future

Resuscitation Research Group White Paper

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RESUSCITATION RESEARCH GROUP

Contents

Preface

This report aims to provide the Clinical Directorate at Scottish Government and Members of Scottish Parliament with a review of public access defibrillators (PAD) and their utility for out-of-hospital cardiac arrest (OHCA) in Scotland. It also aims to answer questions about PAD that are commonly asked, with the goal of mitigating potential misunderstandings about when PAD may or may not provide benefit.

This document should be read in conjunction with Scotland's Out-of-Hospital Cardiac Arrest Strategy 2021-26, which details the strategic direction laid out by the Scottish Government in improving outcomes for OHCA and the role of PAD in doing so. The Scottish OHCA Strategy document can be accessed at: https://www.gov.scot/publications/scotlands-out-hospital-cardiac-arrest-strategy-2021-2026/

This report is composed of two parts. The first part is a policy brief that provides a narrative review of the benefits and limitations of PAD, as well as how PAD might be best applied in the Scottish context. The second part is a set of frequently asked questions regarding PAD, particularly regarding their utility and their role in improving outcomes after OHCA in Scotland. We provide short answers with references to the policy brief and external sources for further information.

The contents of this document have been shared with Scotland's Out-of-Hospital Cardiac Arrest Strategy 2021-26 Delivery Group members, and Save a Life for Scotland partners. This consultation exercise aimed to take into account the perspectives of those involved in OHCA improvement work across Scotland; however, the views expressed here are our own.

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Part One: Policy Brief

Introduction

Out-of-hospital cardiac arrest (OHCA) is a time-critical medical emergency in which the heart is suddenly and unexpectedly unable to maintain a regular rhythm and can no longer pump blood around the body. In Scotland, the Scottish Ambulance Service (SAS) attempts resuscitation for around 3,200 OHCA each year, and despite recent improvements in survival, fewer than 1 in 10 patients will be discharged from hospital alive.[1,2] Prompt medical treatment of OHCA is essential as the likelihood of survival can decrease by 7-10% for each minute's delay until help arrives.[3–5]

OHCA can occur for a variety of reasons, with about one quarter of cases resulting from a disturbance in the electrical signals which control heart muscle contraction.[2] This is called ventricular fibrillation (VF), the most treatable type of OHCA. The only effective treatment for VF is rapid 'defibrillation', where a therapeutic dose of electrical energy is passed through the chest with the goal of restarting the heart's normal rhythm. In order to be effective, defibrillation must be performed as soon after the onset of cardiac arrest as possible. Equipment such as automated external defibrillators (AED) are designed to be used by anyone, even those without any medical training, as the machine automatically determines whether a patient needs defibrillation then can safely deliver the electric shock.

To maximise the likelihood of defibrillators being readily available to bystanders in the event of a nearby OHCA, public access defibrillators (PAD) have been deployed in a range of locations around the world, including Scotland. PAD placement programmes are a priority in Scotland's strategy for OHCA.[6,7] Although there is much academic literature supporting the use of PAD, there remains uncertainty regarding how PAD should best be deployed from a health policy perspective. This document will address key questions relating to PAD using evidence from published literature in addition to data collected by SAS. These questions include:

1. What is the evidence for the usefulness of PAD?
2. How should PAD be deployed?
3. Where are PAD most effective?
4. How can we better mobilise people to use PAD?

What is the evidence for PAD?

Benefits of PAD

PAD were first deployed in the 1990s in controlled, highly supervised settings such as casinos, airports, and onboard aircraft.[8–10] These settings are staffed by personnel who typically receive first aid training and as such were able to respond to OHCA victims quickly, allowing for PAD to be applied well before the arrival of emergency services. Similarly, a large-scale trial in North American communities in the early 2000s showed that volunteers responding to OHCA had double the likelihood of patient survival when they were equipped with PAD.[11] These studies show that timely response with PAD can improve OHCA survival.

Several studies have considered the impact of placing PAD in the open and allowing any member of the public (not just those with prior first aid training) to retrieve the PAD for use at a nearby OHCA. These studies showed that for OHCA occurring in public areas, PAD can be effective in improving the likelihood of survival by around two-fold, and in one study, up to seven-fold.[11–17] Further, as more PAD were deployed in the community over time, rates of PAD usage for OHCA increased.[18,19] These findings suggest that PAD can be an effective public health intervention to improve OHCA survival.

The use of PAD has been incorporated into many first aid programmes. In controlled experiments, people without prior medical training were able to quickly learn and use PAD, including even schoolchildren.[20–24] Ambulance service call handlers can also coach bystanders to successfully use a PAD.[25,26] Owing to the potential effectiveness and ease of use for PAD, international organisations such as the American Heart Association and European Resuscitation Council promote the deployment of PAD in areas where the likelihood of OHCA is high,[27,28] and the International Liaison Committee on Resuscitation recommends the implementation of large-scale PAD programmes.[29]

In Scotland, the number of PAD registered with SAS has increased over time, having more than doubled over the past three years (Figure 1) with the COVID-19 pandemic having little to no impact on PAD deployment.[2]

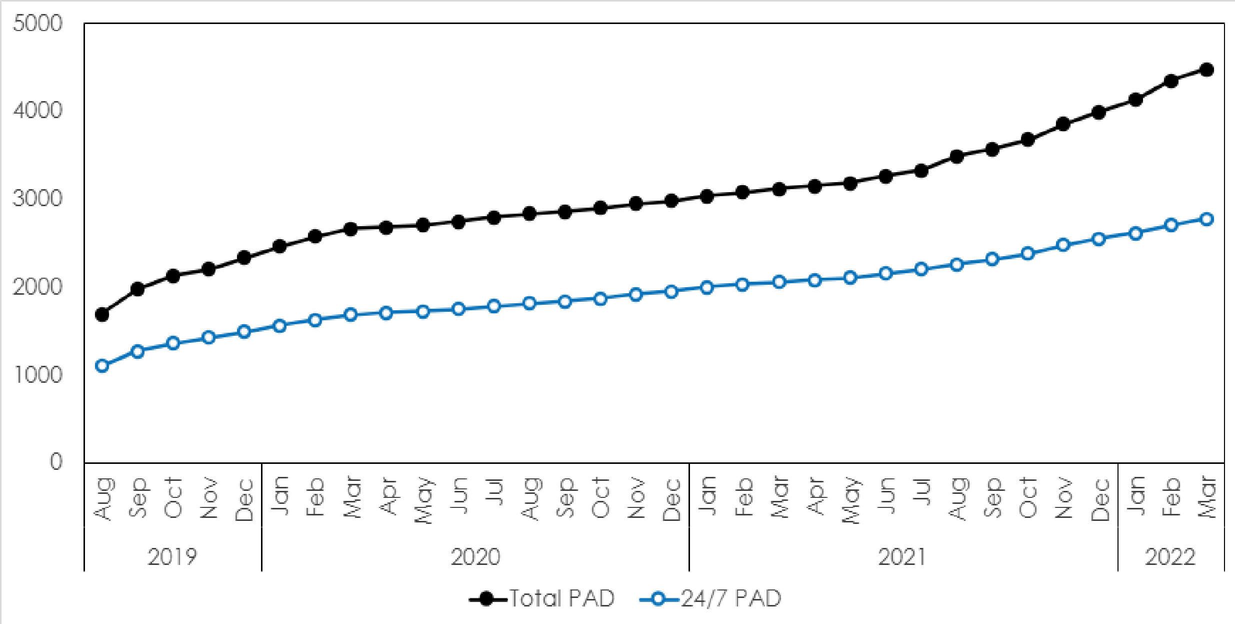

Figure 1 shows the total number of PAD (black) and the number of PAD available 24/7 (blue) registered and active on the UK national defibrillator network ('The Circuit') from August 2019 to March 2022.[2]

The Chain of PAD

Several steps have to first be taken before an OHCA patient can be successfully defibrillated with a PAD. These steps are collectively known as the 'chain of public access defibrillation' (Figure 2),[30] referring to the idea that these steps are interdependent and successful defibrillation can only occur if all these steps are in place.

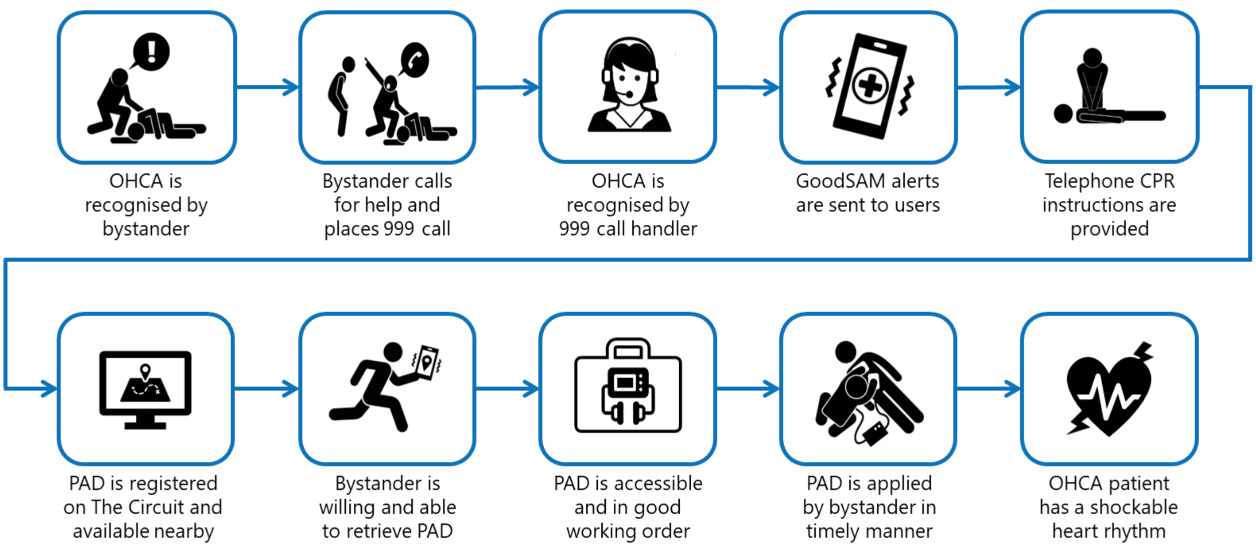

Figure 2 shows the 'Chain of Public Access Defibrillation' adapted from Ringh and colleagues.[30]

PAD first need to be placed in the community and registered with the national defibrillator network (also known as 'The Circuit'). When an OHCA occurs, bystanders who discover the patient need to recognise the problem and call for help by phoning 999.

Once on the line, SAS call handlers in the Ambulance Control Centre (ACC) need to quickly recognise OHCA, identify whether there are registered PAD nearby, and ask if there are bystanders who are able and willing to retrieve the PAD. Call handlers will also provide CPR instructions over the phone. Additional bystanders may be automatically alerted to a nearby OHCA through the GoodSAM smartphone app, launched in Scotland in October 2022 and which can increase the number of people available to retrieve a nearby PAD.

Responders tasked by ACC with retrieving PAD need to be able to easily identify the PAD location through signage or prior knowledge, retrieve the PAD from its cabinet (unlocking the cabinet if necessary), and return with the PAD to the OHCA location. The PAD must be in good working order in order to be deployed by the bystander. Once the PAD is applied to the patient and turned on, the patient must have a shockable heart rhythm for the defibrillating electric shock to be applied.

Only with the successful implementation of all of these steps can successful PAD-based defibrillation then occur. Thus, it is crucial to establish a strong 'system of care' for OHCA response such that the likelihood of successful bystander defibrillation is maximised.

Limitations of PAD

Rates of PAD use are low

Although PAD are effective when they are deployed promptly at OHCA, studies around the world have shown that rates of bystander-applied defibrillation remain very low, with OHCA victims defibrillated prior to ambulance arrival less than 10% of the time.[18,19,31–35] Over the past three years, an average of 8% of OHCA where resuscitation was attempted by the ambulance service in Scotland had a PAD applied before the arrival of SAS crews (Figure 3).[1,2] It should however be noted that PAD usage rates have increased over the past several years, notwithstanding temporary dips during the early stages of the COVID-19 pandemic.

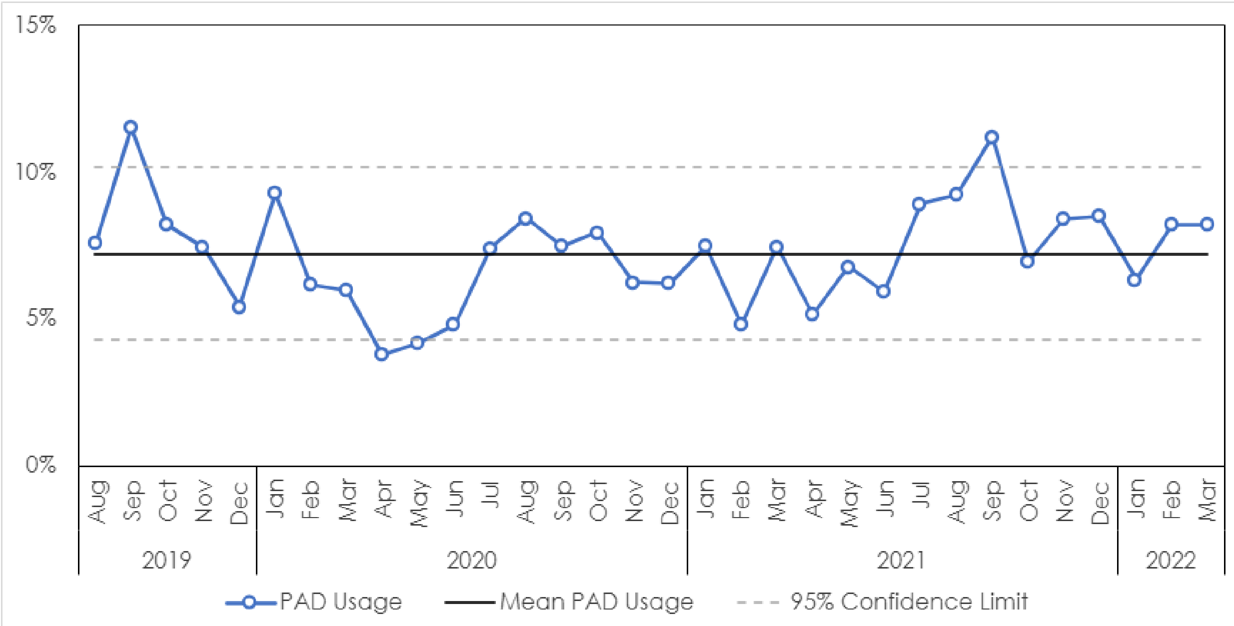

Figure 3 shows the proportion of OHCA across Scotland where a PAD was deployed by the public before the arrival of SAS crews from August 2019 to March 2022.[2] The average (or mean) PAD usage rate (black) and the 95% confidence limits (grey, dashed) are also provided for reference.

PAD need to be in the right place

One factor associated with the low rates of PAD usage is the location of PAD.[34,36] In order for a PAD to be used it must be near enough for a bystander to go and find it, unlock it (if necessary) and bring it back to the patient before the arrival of SAS. This means that PAD must be located near OHCA. Research in a range of countries, including Scotland, has identified generally poor alignment between locations where PAD have been placed and locations where OHCA frequently occur.[37–39]

PAD need to be located in the right communities

In addition, a recent study of PAD in Scotland found poor alignment between PAD and OHCA locations across levels of socioeconomic deprivation as measured by the Scottish Index of Multiple Deprivation (SIMD).[39] The most deprived 20% of census data zones (SIMD Quintile 1) had the greatest share of OHCA occurrence but the lowest share of registered PAD (Figure 4), and had consistently lower rates of PAD usage (Figure 5) compared to data zones experiencing less deprivation. In conjunction with literature both within Scotland and abroad showing that socioeconomically deprived areas are generally at higher risk of OHCA,[39–43] have lower rates of PAD deployment,[39,43,44] and suffer from poorer OHCA outcomes,[1,2,45–47] these findings suggest that the current deployment of PAD is inequitable across socioeconomic levels.

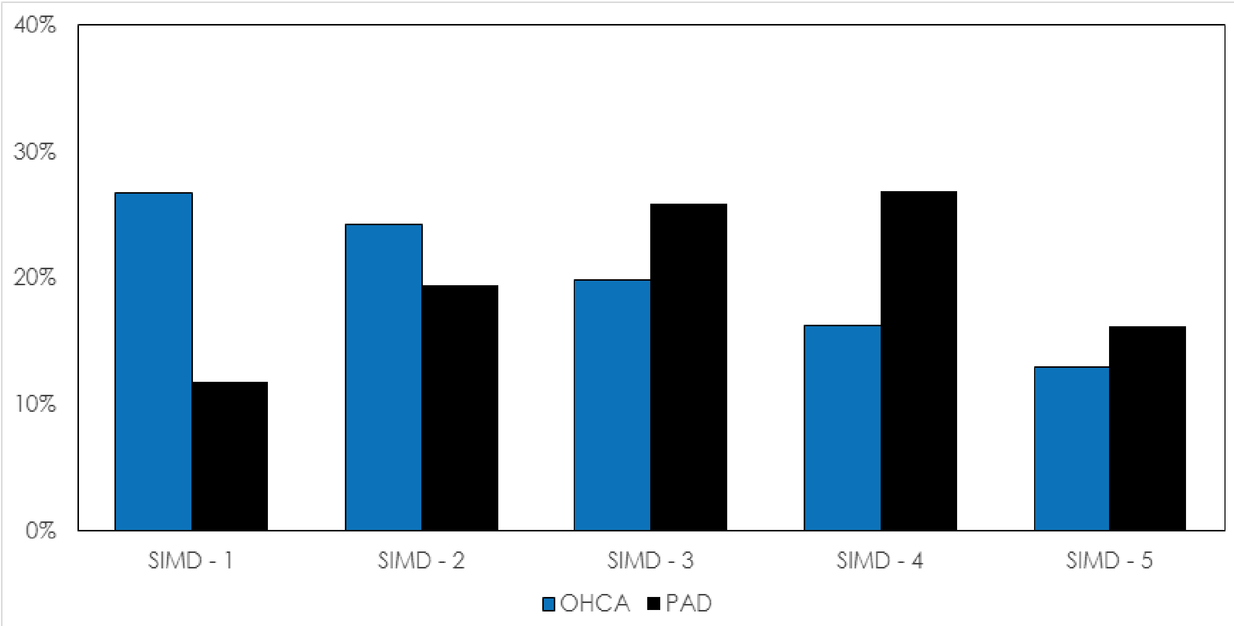

Figure 4 shows the distribution of OHCA (blue) and PAD (black) locations by SIMD quintile from August 2019 to March 2022.[2] Quintile 1 (furthest left) represents the most deprived 20% of Scotland's census data zones, with higher quintile numbers indicating lower levels of deprivation.

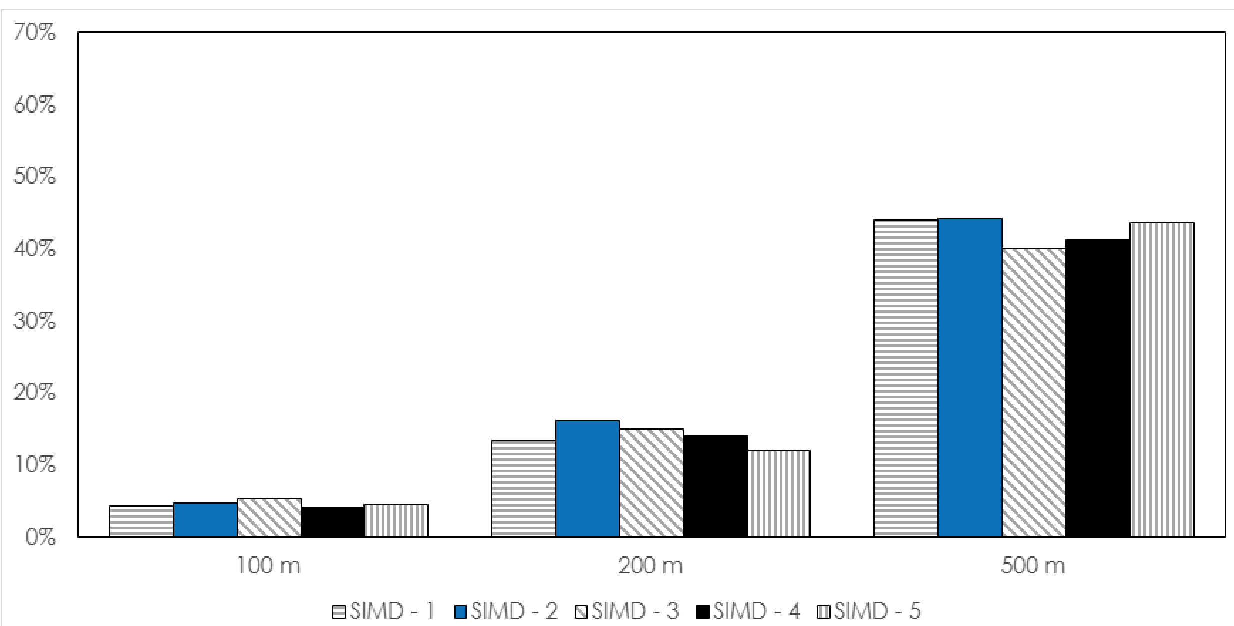

Figure 5 shows the proportion of OHCA occurring within 100 metres, 200 metres and 500 metres of a registered PAD by SIMD quintile from August 2019 to March 2022.[2] Quintile 1 (furthest left, horizonal shading) represents the most deprived 20% of Scotland's census data zones, with higher quintile numbers indicating lower levels of deprivation.

PAD need to be located near OHCA

Another factor associated with low PAD usage rates is the availability and logistics of PAD. Put simply, existing PAD are generally too far away from the OHCA location to be used in a timely manner, with less than 10% of all OHCA being within 100 m of the nearest PAD (Figure 6).[2] Further, research has shown that increased distance between OHCA and the nearest PAD is associated with lower rates of PAD usage and OHCA survival.[36,48,49] Despite a doubling of the number of PAD placed in communities across Scotland 2019-22 (Figure 1), the number of OHCA occurring within the optimal range of a PAD has not increased to the same degree during the same time period (Figure 6).

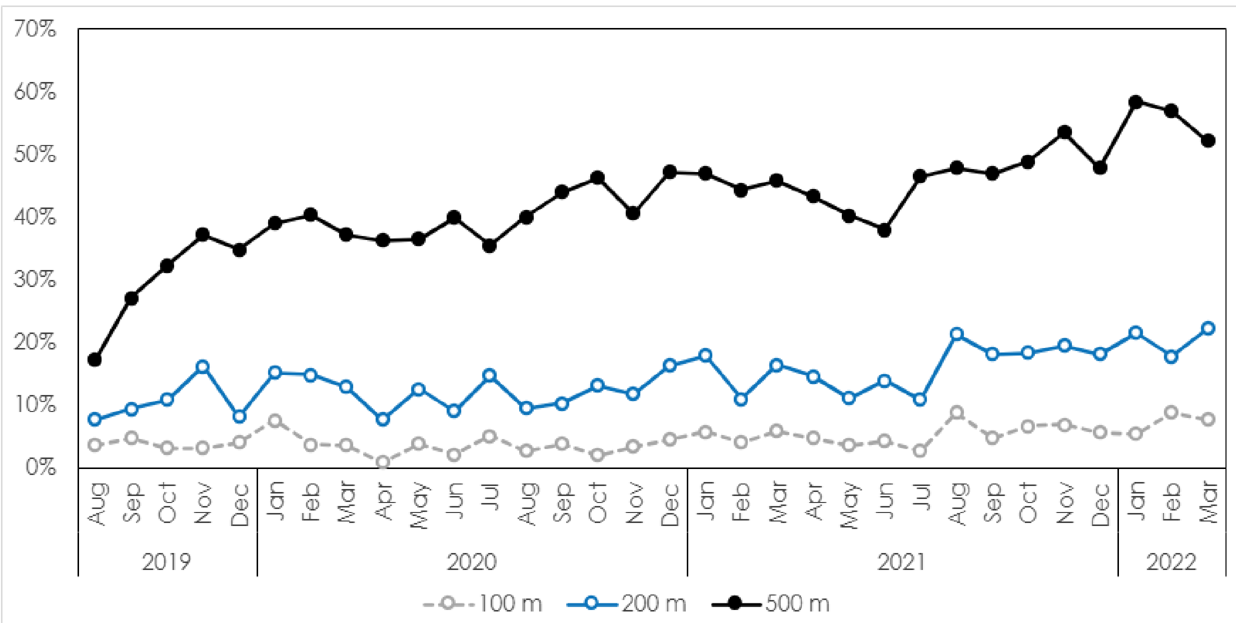

Figure 6 shows the proportion of OHCA occurring within 100 metres (grey, dashed line), 200 metres (blue, solid line), and 500 metres (black, solid line) a registered PAD in Scotland from August 2019 to March 2022. [2]

PAD need to be accessible when needed

Studies from other countries have shown that up to one-half of all PAD are not accessible to the public outside of conventional business hours and on weekends.[50–54] For OHCA that occur during these times, PAD that are too far away or situated behind locked doors lead to low likelihood of PAD usage, even if there are able and willing bystanders nearby.[36,51,53–58] Unfortunately, it appears that in Scotland although the number of PAD in the community is increasing, the proportion which is available 24/7 is getting smaller (Figure 1). In order to maximise PAD availability they are usually best mounted on the outside of buildings.

PAD are also often secured in locked cabinets. In Jan 2023, one-third of the 5629 PAD in Scotland registered on the Circuit were located within locked cabinets. PAD are expensive items of equipment, and it is not unexpected that those who fundraise to place them in the community wish to safeguard their investment. Whilst there is scant evidence (beyond the anecdotal) about the scale of PAD theft and vandalism, or the effectiveness of locked cabinets, it is likely that locking PAD away introduces an additional delay for bystanders attempting to retrieve the defibrillator and lowers the likelihood of successful PAD application prior to arrival of emergency services.[59]

Bystanders need confidence to effectively use PAD

The human component in the Chain of PAD also presents challenges with PAD deployment and usage. Surveyed bystanders have reported difficulties finding PAD due to lack of knowledge regarding nearby PAD locations and lack of adequate guiding signage.[55] When bystanders are able to retrieve a PAD, they often face fears of not knowing how to use the PAD and potentially harming the OHCA patient in the process: this is especially prevalent for responders who have not been trained in PAD use.[60,61] Despite the fact that PAD are designed to be used effectively by the public without prior instruction, simulation studies suggest that bystanders only rarely operate a PAD without issue.[62] Inconsistent levels of bystander training and willingness across different parts of Scotland may partly explain differences in rates of PAD usage.

Overcoming limitations in Scotland

Supporting the location of PAD in places where they are most likely to be used

The Scottish Ambulance Service tracks PAD usage statistics as part of its recordkeeping and continuous quality improvement processes for OHCA. SAS, in collaboration with the Resuscitation Research Group at the University of Edinburgh (RRG), are utilising data analytics and artificial intelligence methods to determine areas within Scotland where PAD are most likely to be used, so that the effectiveness of deployed PAD can be maximised over their service lives. Our intention is that this information will then be disseminated to community partner organisations and interested individuals through an interactive web application called PADmap, which will display recommended locations for new PAD to be placed within communities across Scotland to maximise their anticipated effectiveness. The PADmap prototype interface was developed after extensive consultation with potential users (Figure 7), and funds are currently being sought to build the public facing iteration. PADmap will be hosted by SAS and will be integrated with routinely collected OHCA data and PAD locations obtained from The Circuit,[63] such that the information displayed on PADmap is kept up to date as new PAD are placed throughout Scotland.

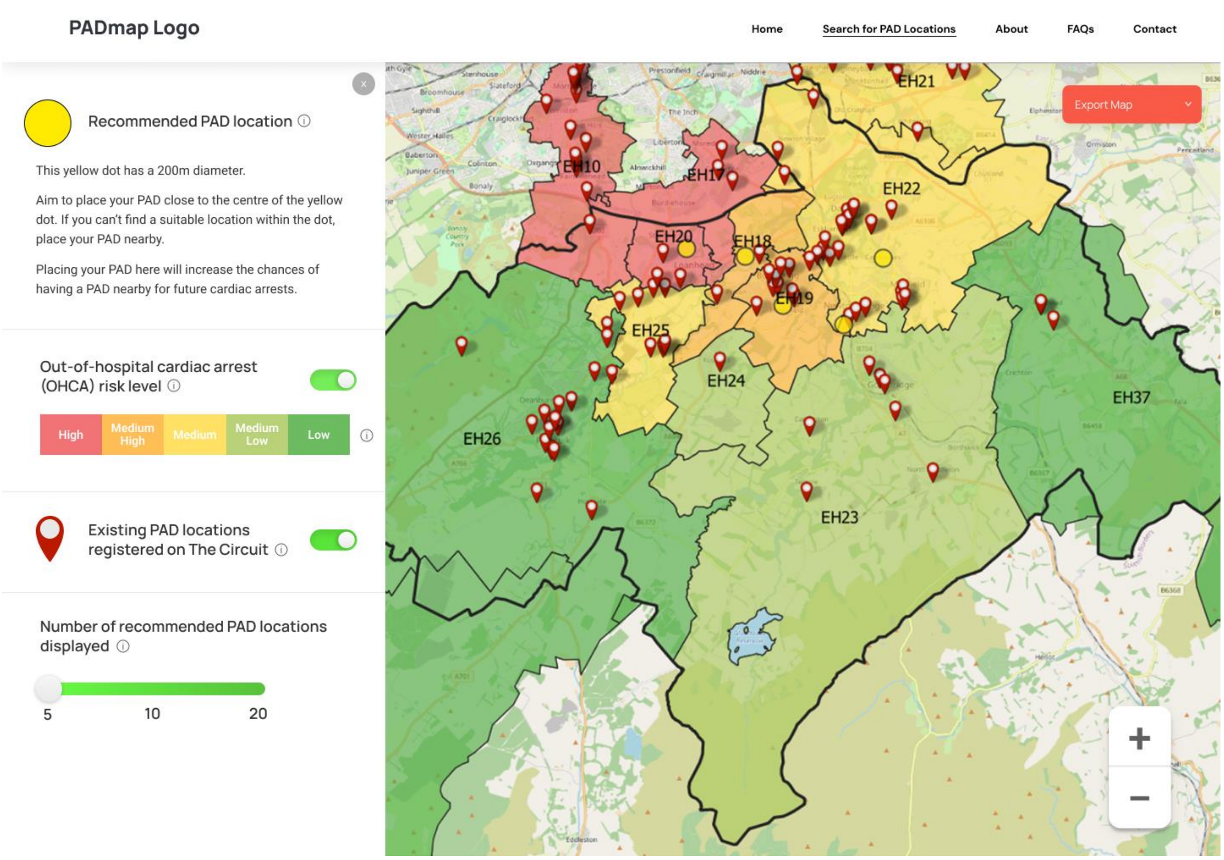

Figure 7 shows a prototype of the PADmap web application showcasing ideal locations for new PAD to be placed. Existing registered PAD locations from The Circuit (red markers) and recommended new PAD locations (yellow circles) are overlaid on top of OHCA risk levels per postcode, ranging from low (green) to high (red).

Familiarising the public with PAD

The Save A Life for Scotland campaign (SALFS) is working with national and community-level organisations to familiarise individuals with CPR and PAD, with the goal of training a total of 1 million people across Scotland by 2026.[7] SALFS has four key strategic work streams, focusing on engaging with young people, communities, and disadvantaged groups, and influencing Scottish culture regarding OHCA. This approach enables people of all ages and backgrounds to learn how to use PAD, which in turn will empower them to retrieve and apply PAD for OHCA in their communities. Through these initiatives that increase both the quantity of deployed PAD as well as awareness of PAD throughout communities in Scotland, PAD usage rates are expected to continue to increase into the future.

How should PAD be deployed in Scotland?

More PAD doesn't necessarily mean more PAD usage

Existing research literature is limited in quantifying the relationship between PAD deployment and resulting PAD usage.[30,53,64] The question reamains, if more PAD are made available in communities, will PAD usage rates increase? Analysis of Scottish OHCA data showed that despite the number of PAD more than doubling between 2019 and 2022, the proportions of OHCA occurring within 100 m of a PAD and the rate of PAD usage for OHCA did not increase at similar rates during the same time period.[2] This underlines the fact that for PAD to be useful, they must be placed in the locations where OHCA are likely to occur.

Through initiatives such as PADmap, analysis of registered PAD data from The Circuit, and regular monitoring of OHCA data by SAS, geographical and demographic factors that affect PAD usage can be determined, the relationship between PAD deployment levels and PAD usage can be quantified, and characteristics of communities that benefit the most from increased PAD deployment can be identified. Likewise, descriptive data analytics can also help determine the extent to which targeted PAD education in specific communities leads to changes in rates of bystander PAD usage as well as contributing factors that lead to inequalities of PAD usage across different health boards and SIMD levels.

Using AI to support data-driven PAD installation in high-risk areas

Our recommended approach in Scotland is to utilise data-driven PAD placement based on the occurrence of OHCA locations, which will allow us to predict incidence of future OHCA at the community level and determine optimal locations for new PAD accordingly. This will be done using data analytics and artificial intelligence techniques that have shown ability to outperform historical and guideline-recommended PAD locations;[51,65–68] SAS has begun integrating these methodologies into PAD location analyses.[7,39] Optimised PAD locations will be shared with local health and social care partnerships, community partner agencies, and interested individuals through the PADmap platform (see above). Enabling the dissemination of information to those who purchase and place PAD in their communities (such as in easily identifiable businesses that are in areas with high likelihood of OHCA[52]) is likely to increase PAD usage in such places.

Fairness vs efficiency of PAD allocation

As the number of PAD increases, an important question that has yet to be addressed is whether PAD are fairly allocated across health boards, council areas, and SIMD quartiles. In contrast to a purely efficiency-focused approach where the goal is to maximise the successful useage of PAD nationally, regardless of in which areas they are placed, the concept of fairness in this context can be understood as either an equal allocation of deployed PAD or an equal benefit to be received in each area. This is important to address because although current rates of PAD usage are low throughout the country, the distribution of PAD is substantially different across health boards, council areas, and SIMD quartiles.

Preliminary analyses conducted by RRG suggest that incorporating fairness into data-driven PAD placement models within council areas results in a small loss of PAD accessibility, but can greatly improve fairness across council wards.[69] RRG will continue this work of quantifying the relationship between PAD deployment efficiency versus fairness, and will work with academic and the international resuscitation community to understand whether and how places with centrally organised PAD deployment incorporate fairness concepts into their decision making.

Where would PAD be most effective?

Can we predict where OHCA are most likely to happen?

Existing studies analysing the clinical effectiveness of PAD have largely focused on OHCA occurring in public areas, such as shopping centres and transit stations, as these locations tend to have high levels of foot traffic and thus are more likely to have OHCAs occur as well as having responders nearby.[70–73] However, OHCA occurring in public areas only correspond to approximately 20% of all OHCA, with the rest occurring in private and residential locations.[12,14,30,32,33]

Although some literature suggests that OHCA hotspots generally do not change over time,[66,74] it is not currently known whether that is the case for Scotland. As such, time-based analyses can be utilised to determine the temporal stability of OHCA occurring in Scotland, produce risk mappings for OHCA in Scotland and determine communities and areas at high risk of OHCA in the future, and update our predictions as new OHCA data becomes available from SAS and newly registered PAD become available through The Circuit. This continuously evolving, evidence-driven approach will help us make better projections when determining where in Scotland will stand to benefit the most from PAD, both in terms of exact locations or location types, as well as at the community or health board level.

Are PAD cost-effective?

Studies analysing the cost-effectiveness of PAD deployment have yielded mixed results. Based on expected rates of use over their service life, PAD have been shown to be cost-effective in public urban areas where footfall levels are expected to be high, such as on high streets and shopping centres.[75–79] However, other studies have suggested that PAD would not be cost-effective if deployed nationally purely based on location type, such as in all homes or in all shops.[80,81]

This lack of clarity may be due to the heterogeneity regarding PAD locations and deployment strategies considered. Through the evidence-driven PAD deployment policy proposed for Scotland, the cost-effectiveness of already-deployed PAD as well as potential changes in cost-effectiveness through data-driven PAD placement can be estimated. Such analyses can then account for changing parameters in cost and benefit to patients based on information pertinent to the Scottish context, and can also be performed at varying scales such as at the community level, health board or national level, or across socioeconomic levels by using SIMD quartiles. These analyses can then help determine areas that may have the most cost-effective PAD deployment and areas where the cost-effectiveness may be lower and thus alternative OHCA response strategies may be more viable.

How close to an OHCA does a PAD need to be in order to be used?

Existing literature has assumed that PAD are generally useful as long as they are near to an OHCA. This distance varies between 100 to 500 metres, and may refer to either a straight-line ('as the crow flies') or a road-based distance.[36,39,51,58,65–68,82,83] SAS currently uses a 500 metre straight-line range when alerting bystanders to nearby PAD. Intuitively, the closer a PAD is to an OHCA, the more likely it will be used; however, it is unclear how far bystanders are willing or able to go to retrieve a PAD and return before the arrival of ambulance personnel.

Using OHCA data, the relationship between distance to the nearest PAD vs. likelihood of PAD usage can be estimated, which in turn will affect projected utility of newly placed PAD. PAD may also be brought by community first responders.[84] This analysis will also help to determine the benefit that current community first responders provide for OHCA, as well as areas currently underserved and have the greatest potential for benefit through further recruitment of ‘mobile PAD’ brought by community responders.

The launch of GoodSAM, a mobile application that alerts bystanders to nearby OHCA, will provide SAS with geotagged measurements of how far bystanders travel when responding to nearby OHCA. This can in turn help determine whether the current 500 metre retrieval range should be adjusted, or potentially even customised depending on the region of the OHCA.

How far should the ambulance service send a bystander to retrieve a PAD?

The ‘retrieval range’ refers to the maximum distance that a SAS call handler will send a bystander to fetch a PAD. SAS currently uses a 500 metre ‘as the crow flies’ retrieval range from the OHCA location — this is the same distance used by most ambulance services across the UK.

It is important to note that the retrieval range is not the same as the ‘functional range’ of a PAD, which refers to the maximum distance that a bystander can travel to fetch a PAD, return to the OHCA patient, and apply the PAD prior to the arrival of emergency services. The functional range is dependent on several factors such as terrain, road geography, and the speed of the bystander, whereas the retrieval range is a fixed distance used for every OHCA regardless of location.

A Swedish study that tracked bystanders sent to fetch PADs using their mobile phones found that the estimated traveling speed of a responder was 2.3 m/s or 5.1 mph among all volunteers and 1.8 m/s or 4.0 mph in areas with high population density.[85] Using these real-world data translates to a functional range of around 150-200 m to meet the 1.5-minute one-way (3-minute round-trip) target for PAD retrieval suggested by some authorities,[86] although there is currently no commonly-accepted guideline stipulating either a functional or retrieval range.

As GoodSAM becomes increasingly utilised across Scotland, SAS can utilise geotagged travel data to determine what the functional range is for OHCA and whether it varies across communities in Scotland. This information can then be used to determine whether the 500 metre retrieval range is appropriate for OHCA across all of Scotland, or if the retrieval range should be customised depending on the location of the OHCA.

How can we better mobilise people to use PAD?

Prepare the public to act

The likelihood of bystander PAD usage for OHCA is greatly affected by the characteristics of the bystanders themselves. Studies show that untrained bystanders are generally unwilling to use a PAD,[55,87] but that having received PAD training substantially increases their willingness to do so.[23,88] By leveraging OHCA data with information from training-focused partner agencies such as SALFS, St John Scotland and St Andrew's First Aid among others, a better understanding of the extent to which PAD training is improving bystander response for OHCA and their effect on patient outcomes can be attained, which can further drive targeted campaigns in specific communities.

RRG has also embarked on research to identify how to better facilitate PAD training for individuals through liaising with partners abroad who have implemented training programmes in schools and in communities, as well as conducting ongoing research into understanding interaction dynamics between bystanders who retrieve and use PAD, the SAS dispatcher who relays instructions to the bystander, and the PAD itself. Such initiatives and partnerships will not only help improve the understanding of how to make PAD training more readily available to the Scottish community, but also how to further break down barriers to PAD usage that currently exist both in Scotland and around the world.

Encourage rational, data-driven placement of PAD

Enacting legislation to mandate deployment of PAD in designated places and/or to incorporate PAD training in schools have been discussed as potential solutions in Scotland, based on similar legislation already put in place in Denmark and North America.[89–93] However, studies have identified barriers that lead to non-compliance of PAD placement and registration with emergency services,[26,55,94] as well as poor quality or complete lack of PAD training in schools even after having been made mandatory.[91,93] As such, it is not clear whether PAD usage has changed as a result of such legislation. RRG will work with collaborators in other countries where these types of legislation have been enacted in order to determine whether legislation and enforcement of these policies will actually lead to improved familiarity of PAD amongst the population, as well as whether benefit for OHCA can be attained. Given the paucity of strong evidence, it is unlikely that enacting legislation to mandate PAD deployment will be effective at present.

Aftercare for bystanders

Bystanders who respond to OHCA may be subject to anxiety and uncertainty about whether they were able to help; this emotional turmoil is likely to affect their willingness to respond to OHCA in the future. To that end, SAS and SALFS are establishing a support portal for bystanders who respond to OHCA, providing them with resources to understand their own experience, connect with other responders, and seek professional assistance if required.[95] This will be modelled after the Bystander Support Network, which provides a similar service for responders and witnesses to OHCA in Canada.[96] Through this programme, those who respond to OHCA will be equipped with the means to navigate their experience and be encouraged to respond to similar events in the future.

Concluding Summary

Although PAD are effective at improving survival from OHCA, PAD usage rates remain low both in Scotland and around the world. Factors that contribute to low PAD usage can broadly be summarised into the following themes: poor placement of existing PAD relative to OHCA locations; unavailability and inaccessibility of PAD even in areas where OHCA occur; and reluctance for bystanders to use PAD in an emergency.

In conjunction with academic and community partners, SAS is leading initiatives to utilise a data-driven, optimised approach to PAD deployment that encompasses ideal placement of PAD in communities, maximising accessibility and ease of use for deployed PAD, and enhancing training of community members so that PAD can be used effectively and in a timely manner.

It is important to remember that although PAD deployment is an effective initiative to improve OHCA response, it is only a piece within the overall OHCA system of care, and is not meant to be a catch-all approach. Integration with other existing response mechanisms employed by SAS such as ambulance crews, resuscitation response units, and community first responders, as well as continued education initiatives to increase rates of bystander-initiated resuscitation, will ensure that OHCA victims in Scotland receive the highest quality of response possible in order to maximise their chances of survival.

Part Two: Frequently Asked Questions

This section contains a list of frequently asked questions regarding the utility of PAD, specifically in the Scottish context. Questions have been organised into the following themes:

- Quantities and Locations of PAD
- Practicalities and Logistics of PAD
- Future Developments in Defibrillation

Quantities and Locations of PAD

1. How many PAD do we need in Scotland? How many PAD do we need in [area]?

The number of PAD required in a given area can be calculated by estimating the risk of OHCA in that area using historical OHCA data from SAS. High-risk areas are those where OHCA occurs more frequently than other areas of similar size. In high-risk areas, there should be enough PAD placed within the functional range of any historical OHCA. In areas of lower risk, there should be enough PAD placed within the functional range of where OHCA were most likely to occur, with the understanding that adding more PAD leads to diminished returns.

SAS in collaboration with the University of Edinburgh have been developing AI-driven approaches to determine ideal locations for new PAD to be placed. Through this approach, optimal PAD locations in smaller areas (e.g., council areas, wards) are computed and then aggregated together to determine the number of PAD needed per health board or across all of Scotland (Figure 8). The research team is partnering with Save A Life for Scotland to share these findings with individuals and groups who can put PAD in these locations.

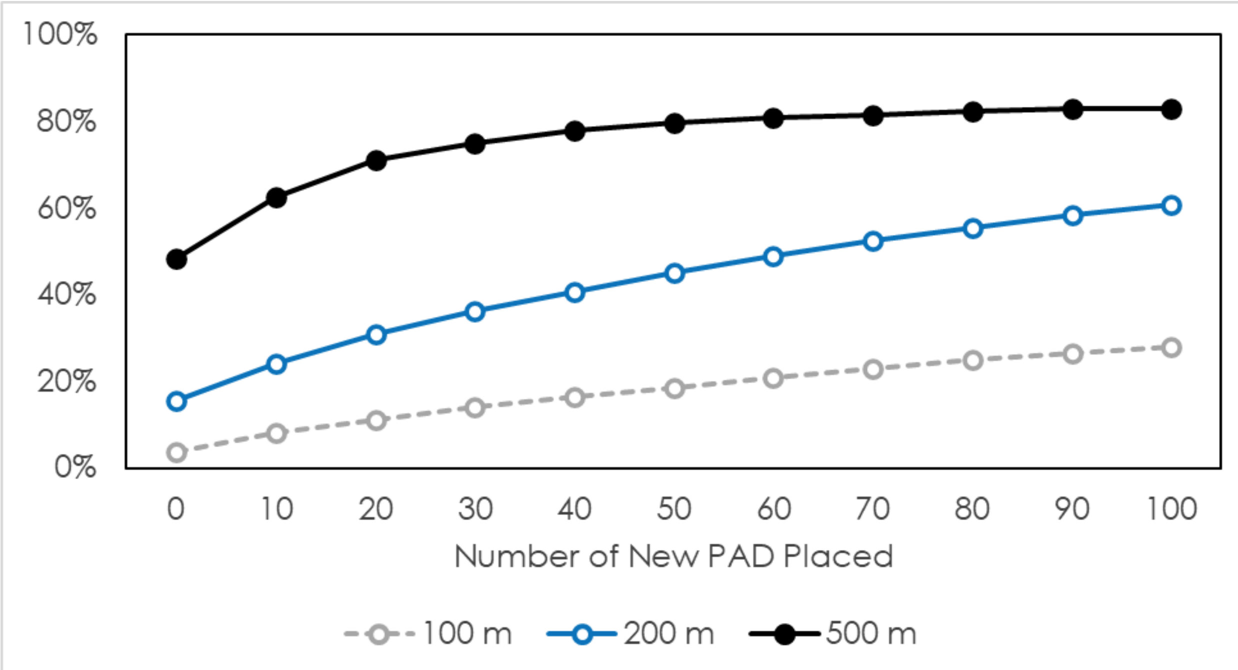

Figure 8 shows the relationship between the number of optimised new PAD locations in a sample area and the resulting number of OHCA within retrieval ranges of 100 metres (grey, dashed line), 200 metres (blue, solid line), and 500 metres (black, solid line).

2. What is the functional range of PAD?

   The functional range of a PAD is the maximum distance from an OHCA at which a PAD is likely to be useful. If a PAD is further away than the functional range, the PAD is likely to be too far away for a bystander to retrieve it before the arrival of the ambulance service. The functional range may vary across different areas based on factors such as terrain, road layout, and population density: thus, determining the functional range is an important factor to consider when planning where PAD should be installed.

3. What is the retrieval range of a PAD?

   The retrieval range of a PAD is the maximum 'as the crow flies' distance that SAS call handlers will send a member of the public to fetch a PAD. The retrieval range is programmed into the computer aided dispatch (CAD) system used by the ambulance service. Once the OHCA location has been determined, the CAD will then automatically alert a call handler if there are PAD available within this predetermined range and their respective locations.

It is important to note that a PAD will only appear on the CAD if it has been registered and maintained on the National Defibrillator Network database, also known as The Circuit. Additionally, SAS will only send a bystander to retrieve a PAD if there is someone else at the scene who can stay and continue to do CPR (chest compressions).

An informal poll of ambulance services around the UK revealed that the majority have set their retrieval range at 500 m, though some services use ranges as large as 1000 m. 1000 m is roughly equivalent to a 7.2-minute 'brisk walk',[85] and the total time required to retrieve the PAD on foot and then deploy it at the scene means that it is likely that a SAS ambulance crew will pre-empt the bystander.

Some ambulance services have considered using a different retrieval range if bystanders may be able to drive to PAD. However, there are concerns that sending an untrained member of the public to drive to retrieve a PAD may introduce significant risk of road traffic accidents.

4. How far away should bystanders be sent to retrieve a PAD?

There currently exists no national or international guidelines stipulating the recommended functional range. A round trip for a bystander to retrieve and deploy a PAD should take less time than it would take SAS to arrive at an OHCA. A '1.5-minute brisk walk' range (meaning a round-trip time of 3 minutes) has previously been suggested by some authorities.[86]

A Swedish study carried out in 2018-19 tracked 2,176 responders to OHCA using their mobile phones and found that the estimated traveling speed of a responder was 2.3 m/s or 5.1 mph among all volunteers and 1.8 m/s or 4.0 mph in areas with high population density.[85] Using these real-world data translates to a functional range of around 150-200 m to meet the 1.5-minute target.

5. Are PAD a good solution for everywhere in Scotland? Are there places where PAD is not the best solution to the problem of early defibrillation after OHCA?

PAD deployment in fixed locations is one method of increasing the likelihood of early defibrillation, and has been shown to be most effective in areas with high footfall and trained bystanders, such as casinos and shopping centres.[8,70,72,73] It is less clear how effective PAD in fixed locations are in more sparsely populated areas with lower density of OHCA.

Other mechanisms for enabling early defibrillation may be more effective in rural and less densely populated areas, such as through trained community responders equipped with defibrillators who are dispatched to OHCAs by the ambulance service. A trial of such a scheme in Scotland — the Sandpiper Wildcat project in rural Grampian — was able to get responders to an OHCA on average 7 minutes before the arrival of SAS crews.[84]

6. Does it make sense to put a PAD in every school in Scotland?

There are a number of reasons why it might make sense to put PAD into schools. The presence of PAD may increase children's familiarity with the devices and lead to them being more willing to use PAD should the need arise later in life. PAD in schools may also be used to teach students about PAD in the context of CPR and first aid training.

The frequency of OHCA in school or near schools (either during school hours or outside of them) is very low.[97] Placement of PAD in schools or on the outside of school buildings is thus probably unlikely to be a cost-effective measure in enabling early defibrillation for OHCA.

7. What are the alternatives to PAD?

There are other methods that aim to enable rapid defibrillation for OHCA, such as:

- Rapid deployment of ambulance services
- Co-response by other groups in the community who carry defibrillators, such as community first responders, Police Scotland, Scottish Fire & Rescue Service, etc.
- Personal ownership of cheaper, single-use defibrillators, which are starting to become available for purchase
- Drone delivery of defibrillators

Practicalities and Logistics of PAD

8. Whose responsibility is it to make sure there are sufficient PAD in the community?

Currently, there is no regulation anywhere in the UK requiring the placement of PAD in the community. The current approach in Scotland is entirely 'bottom up': most PAD placement is driven by individual philanthropists and third-sector organisations.[98]

Recent research analysing the link between PAD locations and the likelihood of OHCA in communities in Scotland suggests that more deprived communities are affected disproportionately by OHCA.[2,39] To achieve both equitable and cost-effectiveness of PAD deployment, an evidence-driven approach consisting of data analysis and dissemination of findings to enable informed PAD placement (e.g., PADmap, Save A Life for Scotland) and implementation of 'top down' direction by central or local government to support and enhance PAD placement is essential.

9. How do I find out how to purchase and install a PAD?

There are a number of resources available for those interested in learning how to purchase, install, and maintain a PAD. Some of these resources are provided below:

- Scottish Government: https://www.gov.scot/publications/out-hospital-cardiac-arrest-guide-public-access-defibrillators/
- Scottish Ambulance Service: https://www.scottishambulance.com/your-community/automated-external-defibrillators/purchasing-an-automated-external-defibrillator/
- British Heart Foundation: https://www.bhf.org.uk/how-you-can-help/how-to-save-a-life/cpr-training-in-communities/defibrillators-in-communities

10. Which PAD should I buy?

There are many different models of automated external defibrillators that can be used as PAD. While features and designs may vary between models, all defibrillators sold in the UK must undergo regulatory approval by the Medicines and Healthcare products Regulatory Agency (MHRA), so the main function of providing appropriate electric shocks to restart an OHCA patient's heart will be effective for all defibrillator models.

11. How can a newly purchased PAD be made known to SAS?

In order for a PAD to be known to SAS in the event of a nearby OHCA, the PAD must be registered on the National Defibrillator Network database, otherwise known as 'The Circuit'. Once registered, the PAD can then appear on the computer aided dispatch (CAD) system used by SAS, and the call handler is then able to direct bystanders to the PAD.

PAD can be registered through The Circuit website: https://www.thecircuit.uk/

12. Are there concerns about theft or vandalism of PAD? Should PAD be kept in locked cabinets?

There is concern that without locked cabinets, PAD will be stolen or tampered with.[98] Theft and vandalism of PAD does occur, although reported rates of PAD theft and vandalism are low, and there is limited evidence as to whether using locked cabinets will affect the likelihood of vandalism.[99] In January 2023 there were 5,629 PAD registered on The Circuit in Scotland, 33% of which were in locked cabinets.[63]

Though there is scant published evidence, there is substantial anecdotal evidence that locked cabinets can cause significant delays in the retrieval of PAD by bystanders. These delays are caused by a number of factors including availability of the passcode and dexterity of bystanders in navigating the locking mechanism.[59] From the perspective of ensuring maximally rapid deployment of PAD to an OHCA in an emergency, unlocked cabinets are almost certainly preferable.

13. Should PAD be located outside or inside buildings?

Locating PAD inside buildings can pose a challenge to bystanders: not all buildings are easy to navigate and not all buildings with PAD may be accessible by the public during off hours. This significantly limits the usefulness of a PAD placed within a building. Research suggests that up to half of OHCA occurring at nighttime or on weekends had PAD that were nearby but were in buildings outwith business hours, meaning they most likely would not have been accessible to those OHCA.[50,51]

An alternative is to place PAD outside, such as on the exterior wall of buildings. However, these PAD must be weather proofed to handle the elements. This can increase maintenance cost and be more susceptible to vandalism, although reported rates of PAD theft and vandalism appear to be low.[98,99]

14. Whose responsibility is it to maintain and look after the PAD? What is involved in looking after the PAD?

Generally, the PAD ‘guardian’ (who is tasked with maintaining the PAD) is either the individual or organisation who owns the location of where the PAD is placed: for example, a PAD placed on the exterior wall of a pub would be the pub owner’s responsibility. There are some exceptions, such as community groups who take on the role of guardianship for PAD in a given area; however, it is up to the PAD owner and these groups to first come to an agreement for this to occur.

PAD guardianship generally involves regular inspection of the PAD and its cabinet for signs of damage, testing the PAD to ensure that it is in working order, and replacement of the battery and adhesive pads (that are applied to the OHCA patient) at regular service intervals or after the PAD has been used.

Future Developments in Defibrillation

15. What about using drones to deliver defibrillators?

Drone delivery of defibrillators is currently being explored as a method to provide faster access to defibrillation for OHCA, especially those that occur in locations challenged by traffic congestion and unavailability of PAD.[59,100] Early stage research suggests that drones can often arrive at OHCA locations prior to ambulance services, especially if a drone network is well-configured using past OHCA data.[101–110] A trial programme of drone-delivered defibrillators for OHCA is currently underway in Sweden,[109,110] with other countries likely to follow in the near future.

Many uncertainties regarding drone delivery of defibrillators remain, such as the reliability of drones, whether bystanders can swiftly retrieve a drone-delivered defibrillator and apply it to the OHCA patient, and the cost-effectiveness of such programmes. Further research is required before a definitive answer can be reached regarding whether drones are a worthwhile investment to improve OHCA outcomes.

16. What is the future of PAD technology?

Ongoing efforts are being made to develop smaller (as small as a mobile phone) and less expensive PAD that can be purchased and carried by individuals.[59] Personally owned PAD can reduce the need for distributed PAD placements if the majority of citizens have personal access to such technology. There is hope to change the PAD availability landscape in the market by increasing availability to PADs and rates of early defibrillation.

17. Will GoodSAM make a difference to PAD use?

GoodSAM is likely to increase the number of bystanders available by alerting them of nearby OHCA and therefore will likely result in more people near OHCA who are able and willing to retrieve PAD.

In contrast to some other crowdsourcing OHCA alert systems, GoodSAM only directs responders to the OHCA location, rather than a split strategy of routing some responders directly to the OHCA and others to nearby PAD first before proceeding to the OHCA. This is a deliberate strategy on behalf of GoodSAM, designed to ensure that starting bystander CPR is prioritised and not inadvertently compromised by attempts to retrieve PAD. Little research has been done into the merits of this approach: one small study did appear to vindicate this strategy,[111] but more analysis is needed before a definitive conclusion can be reached.

18. What research/improvement activity is currently going on in Scotland to improve the rate of early defibrillation and therefore survival after OHCA?

Several ongoing activities are taking place in partnership between SAS, Save A Life for Scotland, the University of Edinburgh, and community groups to improve the rate of early defibrillation to better survival rates of OHCA. Some of the activities are as follows:

- PADmap, a web portal designed to provide users with ideal placement locations for new PAD
- PADsim and PADcomms, research and quality improvement projects aimed to optimise interactions between the SAS call handler, bystander, and PAD
- Novel schemes by some local councils to facilitate guardianship of PADs, help replace consumables and streamline PAD placement
- Academic research into the effectiveness of community cardiac responder schemes, such as the Sandpiper Wildcat scheme in Grampian
- Evaluation of up-and-coming technologies such as drone delivery of defibrillators as well as smaller, lower cost single-use defibrillators
- Launch of GoodSAM to increase the number of bystanders available at OHCA to help with CPR and defibrillation
- Save A Life for Scotland partnership to promote CPR and defibrillator familiarisation, with the goal of engaging 1 million contacts by 2026

19. Are all OHCA receptive to defibrillation? What about OHCA where defibrillation doesn't help?

Successful defibrillation for OHCA requires the patient to have a 'shockable' heart rhythm, specifically known as ventricular fibrillation. Around 75% of OHCA do not present with a shockable rhythm, and the survival rate for these patients is typically very low.[2]

Research shows that OHCA that have faster response or that have CPR applied by bystanders are more likely to have a shockable rhythm.[64,112] Therefore, improving rapid access to PAD can also increase the chances of successful defibrillation and thus can also result in increased chances of survival.

References

1. Clegg G, McGivern G, Bywater D, Short S, Kent A. *Scottish Out-of-Hospital Cardiac Arrest Data Linkage Project: 2018-2019 Results*. Scottish Government; 2020. https://www.gov.scot/publications/scottish-out-hospital-cardiac-arrest-data-linkage-project-2018-19-results/
2. Clegg G, Kent A, Leung B, et al. *Scotland's Out-of-Hospital Cardiac Arrest Report, 2019-2022*. Scottish Ambulance Service; 2022.
3. Valenzuela TD, Roe DJ, Cretin S, Spaite DW, Larsen MP. Estimating effectiveness of cardiac arrest interventions: A logistic regression survival model. *Circulation*. 1997;96(10):3308-3313. doi:10.1161/01.CIR.96.10.3308
4. Larsen MP, Eisenberg MS, Cummins RO, Hallstrom AP. Predicting survival from out-of-hospital cardiac arrest: A graphic model. *Annals of Emergency Medicine*. 1993;22(11):1652-1658. doi:10.1016/S0196-0644(05)81302-2
5. Stoesser CE, Boutilier JJ, Sun CLF, et al. Moderating effects of out-of-hospital cardiac arrest characteristics on the association between EMS response time and survival. *Resuscitation*. 2021;169:31-38. doi:10.1016/j.resuscitation.2021.10.014
6. Scottish Government. *Out-of-Hospital Cardiac Arrest: A Strategy for Scotland*.; 2015. https://www.gov.scot/publications/out-hospital-cardiac-arrest-strategy-scotland/pages/3/
7. Scottish Government. *Scotland's Out-of-Hospital Cardiac Arrest Strategy, 2021-2026.*; 2021.
8. Valenzuela TD, Roe DJ, Nichol G, Clark LL, Spaite DW, Hardman RG. Outcomes of Rapid Defibrillation by Security Officers after Cardiac Arrest in Casinos. *New England Journal of Medicine*. 2002;343(17):1206-1209. doi:10.1056/nejm200010263431701
9. Page RL, Joglar JA, Kowal RC, et al. Use of Automated External Defibrillators by a U.S. Airline. *New England Journal of Medicine*. 2002;343(17):1210-1216. doi:10.1056/nejm200010263431702
10. Caffrey SL, Becker LB. Public Use of Automated External Defibrillators. *The New England Journal of Medicine*. 2002;347(16):1242-1247. doi:10.1056/NEJMoa020932
11. The Public Access Defibrillation Trial Investigators. Public-access defibrillation and survival after out-of-hospital cardiac arrest. *New England Journal of Medicine*. 2004;351(7):637-646. doi:10.1056/NEJMoa040566
12. Eisenburger P, Sterz F, Haugk M, et al. Cardiac arrest in public locations-An independent predictor for better outcome? *Resuscitation*. 2006;70(3):395-403. doi:10.1016/j.resuscitation.2006.02.002
13. Pollack RA, Brown SP, Rea T, et al. Impact of bystander automated external defibrillator use on survival and functional outcomes in shockable observed public cardiac arrests. *Circulation*. 2018;137(20):2104-2113. doi:10.1161/CIRCULATIONAHA.117.030700
14. Hansen SM, Hansen CM, Folke F, et al. Bystander defibrillation for out-of-hospital cardiac arrest in Public vs Residential Locations. *JAMA Cardiology*. 2017;2(5):507-514. doi:10.1001/jamacardio.2017.0008
15. Marenco JP, Wang PJ, Link MS, Homoud MK, Estes NAM. Improving survival from sudden

cardiac arrest: The role of the automated external defibrillator. *Journal of the American Medical Association*. 2001;285(9):1193-1200. doi:10.1001/jama.285.9.1193
16. Blom MT, Beesems SG, Homma PCM, et al. Improved survival after out-of-hospital cardiac arrest and use of automated external defibrillators. *Circulation*. 2014;130(21):1868-1875. doi:10.1161/CIRCULATIONAHA.114.010905
17. Weisfeldt ML, Sitlani CM, Ornato JP, et al. Survival After Application of Automatic External Defibrillators Before Arrival of the Emergency Medical System. Evaluation in the Resuscitation Outcomes Consortium Population of 21 Million. *Journal of the American College of Cardiology*. 2010;55(16):1713-1720. doi:10.1016/j.jacc.2009.11.077
18. Kitamura T, Iwami T, Kawamura T, Nagao K, Tanaka H, Hiraide A. Nationwide Public-Access Defibrillation in Japan. *N Engl J Med*. 2010;362(11):994-1004. doi:10.1056/NEJMoa0906644
19. Wissenberg M, Lippert FK, Folke F, et al. Association of national initiatives to improve cardiac arrest management with rates of bystander intervention and patient survival after out-of-hospital cardiac arrest. *JAMA - Journal of the American Medical Association*. 2013;310(13):1377-1384. doi:10.1001/jama.2013.278483
20. Cummins RO, Schubach JA, Litwin PE, Hearne TR. Training lay persons to use automatic external defibrillators: Success of initial training and one-year retention of skills. *The American Journal of Emergency Medicine*. 1989;7(2):143-149. doi:10.1016/0735-6757(89)90126-5
21. Gundry JW, Comess KA, DeRook FA, Jorgenson D, Bardy GH. Comparison of Naive Sixth-Grade Children With Trained Professionals in the Use of an Automated External Defibrillator. *Circulation*. 1999;100:1703-1707.
22. Moore JE, Eisenberg MS, Cummins RO, Hallstrom A, Litwin P, Carter W. Lay person use of automatic external defibrillation. *Annals of Emergency Medicine*. 1987;16(6):669-672. doi:10.1016/S0196-0644(87)80068-9
23. Woollard M, Whitfield R, Smith A, et al. Skill acquisition and retention in automated external defibrillator (AED) use and CPR by lay responders: a prospective study. *Resuscitation*. 2004;60(1):17-28. doi:10.1016/j.resuscitation.2003.09.006
24. Jorge-Soto C, Abelairas-Gómez C, Barcala-Furelos R, et al. Automated external defibrillation skills by naive schoolchildren. *Resuscitation*. 2016;106:37-41. doi:10.1016/j.resuscitation.2016.06.007
25. Harve H, Jokela J, Tissari A, et al. Can Untrained Laypersons Use a Defibrillator with Dispatcher Assistance? *Academic Emergency Medicine*. 2007;14(7):624-628. doi:10.1111/j.1553-2712.2007.tb01848.x
26. Rea T, Blackwood J, Damon S, Phelps R, Eisenberg M. A link between emergency dispatch and public access AEDs: Potential implications for early defibrillation. *Resuscitation*. 2011;82(8):995-998. doi:10.1016/j.resuscitation.2011.04.011
27. Berg KM, Cheng A, Panchal AR, et al. Part 7: Systems of Care: 2020 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. *Circulation*. 2020;142(16 2):S580-S604. doi:10.1161/CIR.0000000000000899
28. Semeraro F, Greif R, Böttiger BW, et al. European Resuscitation Council Guidelines 2021:

Systems saving lives. *Resuscitation*. 2021;161:80-97. doi:10.1016/j.resuscitation.2021.02.008
29. Travers AH, Perkins GD, Berg RA, et al. Part 3: Adult Basic Life Support and Automated External Defibrillation. *Circulation*. 2015;132(S1):S51-S83. doi:10.1161/CIR.0000000000000272
30. Ringh M, Hollenberg J, Palsgaard-Moeller T, et al. The challenges and possibilities of public access defibrillation. *J Intern Med*. 2018;283(3):238-256. doi:10.1111/joim.12730
31. Hansen CM, Kragholm K, Pearson DA, et al. Association of bystander and first-responder intervention with survival after out-of-hospital cardiac arrest in North Carolina, 2010-2013. *JAMA - Journal of the American Medical Association*. 2015;314(3):255-264. doi:10.1001/jama.2015.7938
32. Buick JE, Drennan IR, Scales DC, et al. Improving Temporal Trends in Survival and Neurological Outcomes After Out-of-Hospital Cardiac Arrest. *Circ: Cardiovascular Quality and Outcomes*. 2018;11(1):e003561. doi:10.1161/CIRCOUTCOMES.117.003561
33. Chan PS, McNally B, Tang F, Kellermann A. Recent trends in survival from out-of-hospital cardiac arrest in the United States. *Circulation*. 2014;130(21):1876-1882. doi:10.1161/CIRCULATIONAHA.114.009711
34. Deakin CD, Shewry E, Gray HH. Public access defibrillation remains out of reach for most victims of out-of-hospital sudden cardiac arrest. *Heart*. 2014;100(8):619-623. doi:10.1136/heartjnl-2013-305030
35. Hawkes C, Booth S, Ji C, et al. Epidemiology and outcomes from out-of-hospital cardiac arrests in England. *Resuscitation*. 2017;110:133-140. doi:10.1016/j.resuscitation.2016.10.030
36. Sondergaard KB, Hansen SM, Pallisgaard JL, et al. Out-of-hospital cardiac arrest: Probability of bystander defibrillation relative to distance to nearest automated external defibrillator. *Resuscitation*. 2018;124:138-144. doi:10.1016/j.resuscitation.2017.11.067
37. Moon S, Vadeboncoeur TF, Kortuem W, et al. Analysis of out-of-hospital cardiac arrest location and public access defibrillator placement in Metropolitan Phoenix, Arizona. *Resuscitation*. 2015;89(C):43-49. doi:10.1016/j.resuscitation.2014.10.029
38. Brooks SC, Hsu JH, Tang SK, Jeyakumar R, Chan TCY. Determining Risk for Out-of-Hospital Cardiac Arrest by Location Type in a Canadian Urban Setting to Guide Future Public Access Defibrillator Placement. *Annals of Emergency Medicine*. 2013;61(5):530-538.e2. doi:10.1016/j.annemergmed.2012.10.037
39. Leung KHB, Brooks SC, Clegg GR, Chan TCY. Socioeconomically equitable public defibrillator placement using mathematical optimization. *Resuscitation*. 2021;166:14-20. doi:10.1016/j.resuscitation.2021.07.002
40. Allan KS, Ray JG, Gozdyra P, et al. High risk neighbourhoods: The effect of neighbourhood level factors on cardiac arrest incidence. *Resuscitation*. 2020;149:100-108. doi:10.1016/j.resuscitation.2020.02.002
41. Reinier K, Stecker EC, Vickers C, Gunson K, Jui J, Chugh SS. Incidence of sudden cardiac arrest is higher in areas of low socioeconomic status: A prospective two year study in a large United States community. *Resuscitation*. 2006;70(2):186-192. doi:10.1016/j.resuscitation.2005.11.018

42. Reinier K, Thomas E, Andrusiek DL, et al. Socioeconomic status and incidence of sudden cardiac arrest. *CMAJ*. 2011;183(15):1705-1712. doi:10.1503/cmaj.101512
43. Dicker B, Garrett N, Wong S, et al. Relationship between socioeconomic factors, distribution of public access defibrillators and incidence of out-of-hospital cardiac arrest. *Resuscitation*. 2019;138:53-58. doi:10.1016/j.resuscitation.2019.02.022
44. Lee SY, Do YK, Shin SD, et al. Community socioeconomic status and public access defibrillators: A multilevel analysis. *Resuscitation*. 2017;120:1-7. doi:10.1016/j.resuscitation.2017.08.012
45. Vaillancourt C, Lui A, De Maio VJ, Wells GA, Stiell IG. Socioeconomic status influences bystander CPR and survival rates for out-of-hospital cardiac arrest victims. *Resuscitation*. 2008;79(3):417-423. doi:10.1016/j.resuscitation.2008.07.012
46. Clarke SO, Schellenbaum GD, Rea TD. Socioeconomic status and survival from out-of-hospital cardiac arrest. *Academic Emergency Medicine*. 2005;12(10):941-947. doi:10.1197/j.aem.2005.05.031
47. Jonsson M, Härkönen J, Ljungman P, et al. Survival after out-of-hospital cardiac arrest is associated with area-level socioeconomic status. *Heart*. 2019;105(8):632-638. doi:10.1136/heartjnl-2018-313838
48. Andelius L, Hansen CM, Lippert F, et al. Will shorter distance between dispatched lay-rescuer and out-of-hospital cardiac arrest increase cardiopulmonary resuscitation and early defibrillation rates? *Resuscitation*. 2018;130:e56-e57. doi:10.1016/j.resuscitation.2018.07.104
49. Sarkisian L, Mickley H, Schakow H, et al. Longer retrieval distances to the automated external defibrillator reduces survival after out-of-hospital cardiac arrest. *Resuscitation*. 2022;170:44-52. doi:10.1016/j.resuscitation.2021.11.001
50. Hansen CM, Wissenberg M, Weeke P, et al. Automated external defibrillators inaccessible to more than half of nearby cardiac arrests in public locations during evening, nighttime, and weekends. *Circulation*. 2013;128(20):2224-2231. doi:10.1161/CIRCULATIONAHA.113.003066
51. Sun CLF, Demirtas D, Brooks SC, Morrison LJ, Chan TCY. Overcoming Spatial and Temporal Barriers to Public Access Defibrillators Via Optimization. *Journal of the American College of Cardiology*. 2016;68(8):836-845. doi:10.1016/j.jacc.2016.03.609
52. Sun CLF, Brooks SC, Morrison LJ, Chan TCY. Ranking businesses and municipal locations by spatiotemporal cardiac arrest risk to guide public defibrillator placement. *Circulation*. 2017;135(12):1104-1119. doi:10.1161/CIRCULATIONAHA.116.025349
53. Karlsson L, Malta Hansen C, Wissenberg M, et al. Automated external defibrillator accessibility is crucial for bystander defibrillation and survival: A registry-based study. *Resuscitation*. 2019;136:30-37. doi:10.1016/j.resuscitation.2019.01.014
54. Deakin CD, Anfield S, Hodgetts GA. Underutilisation of public access defibrillation is related to retrieval distance and time-dependent availability. *Heart*. 2018;104(16):1339-1343. doi:10.1136/heartjnl-2018-312998
55. Smith CM, Lim Choi Keung SN, Khan MO, et al. Barriers and facilitators to public access defibrillation in out-of-hospital cardiac arrest: A systematic review. *European Heart Journal - Quality of Care and Clinical Outcomes*. 2017;3(4):264-273.

doi:10.1093/ehjqcco/qcx023
56. Huig IC, Boonstra L, Gerritsen PC, Hoeks SE. The availability, condition and employability of automated external defibrillators in large city centres in the Netherlands. *Resuscitation*. 2014;85(10):1324-1329. doi:10.1016/j.resuscitation.2014.05.024
57. Siddiq AA, Brooks SC, Chan TCY. Modeling the impact of public access defibrillator range on public location cardiac arrest coverage. *Resuscitation*. 2013;84(7):904-909. doi:10.1016/j.resuscitation.2012.11.019
58. Neves Briard J, De Montigny L, Ross D, De Champlain F, Segal E. Is Distance to the Nearest Registered Public Automated Defibrillator Associated with the Probability of Bystander Shock for Victims of Out-of-Hospital Cardiac Arrest? *Prehospital and Disaster Medicine*. 2018;33(2):153-159. doi:10.1017/S1049023X18000080
59. Brooks SC, Clegg GR, Bray J, et al. Optimizing Outcomes After Out-of-Hospital Cardiac Arrest With Innovative Approaches to Public-Access Defibrillation: A Scientific Statement From the International Liaison Committee on Resuscitation. *Circulation*. 2022;145(13). doi:10.1161/CIR.0000000000001013
60. Lubin J, Chung SS, Williams K. An assessment of public attitudes toward automated external defibrillators. *Resuscitation*. 2004;62(1):43-47. doi:10.1016/j.resuscitation.2004.02.006
61. Resuscitation Council UK. *Cardiopulmonary Resuscitation, Automated Defibrillators and the Law*. Resuscitation Council UK; 2018. https://www.resus.org.uk/sites/default/files/2020-05/CPR%20AEDs%20and%20the%20law%20%285%29.pdf
62. Dong X jie, Zhang L, Yu Y lin, et al. The general public's ability to operate automated external defibrillator: A controlled simulation study. *World J Emerg Med*. 2020;11(4):238. doi:10.5847/wjem.j.1920-8642.2020.04.006
63. British Heart Foundation. The Circuit - The National Defibrillator Network. Accessed May 31, 2021. https://www.thecircuit.uk/
64. Fordyce CB, Hansen CM, Kragholm K, et al. Association of Public Health Initiatives With Outcomes for Out-of-Hospital Cardiac Arrest at Home and in Public Locations. *JAMA Cardiol*. 2017;2(11):1226. doi:10.1001/jamacardio.2017.3471
65. Chan TCY, Li H, Lebovic G, et al. Identifying locations for public access defibrillators using mathematical optimization. *Circulation*. 2013;127(17):1801-1809. doi:10.1161/CIRCULATIONAHA.113.001953
66. Chan TCY, Demirtas D, Kwon RH. Optimizing the deployment of public access defibrillators. *Management Science*. 2016;62(12):3617-3635. doi:10.1287/mnsc.2015.2312
67. Sun CLF, Karlsson L, Torp-Pedersen C, et al. In Silico Trial of Optimized Versus Actual Public Defibrillator Locations. *Journal of the American College of Cardiology*. 2019;74(12):1557-1567. doi:10.1016/j.jacc.2019.06.075
68. Sun CLF, Karlsson L, Morrison LJ, Brooks SC, Folke F, Chan TCY. Effect of Optimized Versus Guidelines-Based Automated External Defibrillator Placement on Out-of-Hospital Cardiac Arrest Coverage: An In Silico Trial. *Journal of the American Heart Association*. 2020;9:e016701. doi:10.1161/jaha.120.016701
69. Leung KHB, Lac D, Chan TCY, Clegg GR. 270 Mathematically optimised public access defibrillator placement – fairness or accessibility? In: *Abstracts*. British Medical Journal

Publishing Group; 2022:A8.1-A8. doi:10.1136/bmjopen-2022-EMS.18

70. Marijon E, Bougouin W, Tafflet M, et al. Population Movement and Sudden Cardiac Arrest Location. *Circulation*. 2015;131(18):1546-1554. doi:10.1161/CIRCULATIONAHA.114.010498
71. Dahan B, Jabre P, Karam N, et al. Optimization of automated external defibrillator deployment outdoors: An evidence-based approach. *Resuscitation*. 2016;108:68-74. doi:10.1016/j.resuscitation.2016.09.010
72. Lee M, Demirtas D, Buick JE, et al. Increased cardiac arrest survival and bystander intervention in enclosed pedestrian walkway systems. *Resuscitation*. 2017;118:1-7. doi:10.1016/j.resuscitation.2017.06.013
73. Folke F, Lippert FK, Nielsen SL, et al. Location of Cardiac Arrest in a City Center: Strategic Placement of Automated External Defibrillators in Public Locations. *Circulation*. 2009;120(6):510-517. doi:10.1161/CIRCULATIONAHA.108.843755
74. Demirtas D, Brooks SC, Morrison LJ, Chan TCY. Spatiotemporal Stability of Public Cardiac Arrests. *Circulation*. 2015;132(S3):A15003.
75. Winkle RA. The effectiveness and cost effectiveness of public-access defibrillation. *Clinical Cardiology*. 2010;33(7):396-399. doi:10.1002/clc.20790
76. Walker A. Cost effectiveness and cost utility model of public place defibrillators in improving survival after prehospital cardiopulmonary arrest. *BMJ*. 2003;327(7427):1316-0. doi:10.1136/bmj.327.7427.1316
77. Gold LS, Eisenberg M. Cost-effectiveness of automated external defibrillators in public places: pro. *Current Opinion in Cardiology*. 2007;22(1):1-4. doi:10.1097/HCO.0b013e32801173c1
78. Andersen LW, Holmberg MJ, Granfeldt A, James LP, Caulley L. Cost-effectiveness of public automated external defibrillators. *Resuscitation*. 2019;138:250-258. doi:10.1016/j.resuscitation.2019.03.029
79. Cram P, Vijan S, Mark Fendrick A. Cost-effectiveness of automated external defibrillator deployment in selected public locations. *J Gen Intern Med*. 2003;18(9):745-754. doi:10.1046/j.1525-1497.2003.21139.x
80. Moran PS, Teljeur C, Masterson S, O’Neill M, Harrington P, Ryan M. Cost-effectiveness of a national public access defibrillation programme. *Resuscitation*. 2015;91:48-55. doi:10.1016/j.resuscitation.2015.03.017
81. Pell JP, Walker A, Cobbe SM. Cost-effectiveness of automated external defibrillators in public places: Con. *Current Opinion in Cardiology*. 2007;22(1):5-10. doi:10.1097/HCO.0b013e3280118fec
82. Karlsson L, Sun CLF, Torp-Pedersen C, et al. Implications for cardiac arrest coverage using straight-line versus route distance to nearest automated external defibrillator. *Resuscitation*. 2021;167:326-335. doi:10.1016/j.resuscitation.2021.07.014
83. Smith CM, Lall R, Spaight R, Fothergill RT, Brown T, Perkins GD. Calculating real-world travel routes instead of straight-line distance in the community response to out-of-hospital cardiac arrest. *Resuscitation Plus*. 2021;8:100176. doi:10.1016/j.resplu.2021.100176
84. Fickling K, Clegg G, Jensen K, Donaldson L, Laird C, Bywater D. PP22 Sandpiper wildcat

project – saving lives after out-of-hospital cardiac arrest in rural grampian. *Emerg Med J*. 2019;36(1):e9.1-e9. doi:10.1136/emermed-2019-999.22
85. Jonsson M, Berglund E, Djärv T, et al. A brisk walk—Real-life travelling speed of lay responders in out-of-hospital cardiac arrest. *Resuscitation*. 2020;151:197-204. doi:10.1016/j.resuscitation.2020.01.043
86. Aufderheide T, Hazinski MF, Nichol G, et al. Community Lay Rescuer Automated External Defibrillation Programs. *Circulation*. 2006;113(9):1260-1270. doi:10.1161/CIRCULATIONAHA.106.172289
87. Schober P, van Dehn FB, Bierens JJLM, Loer SA, Schwarte LA. Public Access Defibrillation: Time to Access the Public. *Annals of Emergency Medicine*. 2011;58(3):240-247. doi:10.1016/j.annemergmed.2010.12.016
88. Hawkes CA, Brown TP, Booth S, et al. Attitudes to Cardiopulmonary Resuscitation and Defibrillator Use: A Survey of UK Adults in 2017. *JAHA*. 2019;8(7):e008267. doi:10.1161/JAHA.117.008267
89. Legislative Assembly of Manitoba. *The Defibrillator Public Access Act*.; 2011. https://web2.gov.mb.ca/bills/39-5/pdf/b020.pdf
90. Legislative Assembly of Ontario. *Defibrillator Registration and Public Access Act*.; 2020. https://www.ontario.ca/laws/statute/s20008
91. Malta Hansen C, Zinckernagel L, Ersbøll AK, et al. Cardiopulmonary Resuscitation Training in Schools Following 8 Years of Mandating Legislation in Denmark: A Nationwide Survey. *JAHA*. 2017;6(3):e004128. doi:10.1161/JAHA.116.004128
92. Brown LE, Lynes C, Carroll T, Halperin H. CPR Instruction in U.S. High Schools. *Journal of the American College of Cardiology*. 2017;70(21):2688-2695. doi:10.1016/j.jacc.2017.09.1101
93. Allan KS, Jefkins TT, O'Neil E, Dorian P, Lin S. Mandating Training Is Not Enough: The State of Cardiopulmonary Resuscitation and Automated External Defibrillator Training in Ontario Schools. *CJC Open*. 2021;3(6):822-826. doi:10.1016/j.cjco.2021.02.008
94. Haskell SE, Post M, Cram P, Atkins DL. Community public access sites: Compliance with American Heart Association recommendations. *Resuscitation*. 2009;80(8):854-858. doi:10.1016/j.resuscitation.2009.04.033
95. Save A Life for Scotland. Support after cardiac arrest. Save A Life for Scotland. Published 2022. Accessed August 8, 2022. https://savealife.scot/get-support/
96. Bystander Support Network. Bystander Support Network. Published 2016. Accessed August 8, 2022. https://www.bystandernetwork.org/
97. Smith CM, Colquhoun MC. Out-of-hospital cardiac arrest in schools: A systematic review. *Resuscitation*. 2015;96:296-302. doi:10.1016/j.resuscitation.2015.08.021
98. Lac D, Wolters MK, Leung KHB, MacInnes L, Clegg GR. Factors affecting public access defibrillator placement decisions in the United Kingdom: A survey study. *Resuscitation Plus*. 2023;13:100348. doi:10.1016/j.resplu.2022.100348
99. Cheema K, O'Connell D, Herz N, et al. P120 The influence of locked automated external defibrillators (AEDs) cabinets on the rates of vandalism and theft. *Resuscitation*. 2022;175:S80. doi:10.1016/S0300-9572(22)00530-5
100. Roberts NB, Ager E, Leith T, et al. Current summary of the evidence in drone-based

emergency medical services care. *Resuscitation Plus*. 2023;13:100347. doi:10.1016/j.resplu.2022.100347
101. Boutilier JJ, Brooks SC, Janmohamed A, et al. Optimizing a Drone Network to Deliver Automated External Defibrillators. *Circulation*. 2017;135(25):2454-2465. doi:10.1161/CIRCULATIONAHA.116.026318
102. Bogle BM, Rosamond WD, Snyder KT, Zègre-Hemsey JK. The Case for Drone-assisted Emergency Response to Cardiac Arrest: An Optimized Statewide Deployment Approach. *North Carolina medical journal*. 2019;80(4):204-212. doi:10.18043/ncm.80.4.204
103. Cheskes S, McLeod SL, Nolan M, et al. Improving Access to Automated External Defibrillators in Rural and Remote Settings: A Drone Delivery Feasibility Study. *Journal of the American Heart Association*. 2020;9(14):e016687. doi:10.1161/JAHA.120.016687
104. Chu J, Leung KHB, Snobelen P, et al. Machine learning-based dispatch of drone-delivered defibrillators for out-of-hospital cardiac arrest. *Resuscitation*. 2021;162:120-127. doi:10.1016/j.resuscitation.2021.02.028
105. Claesson A, Bäckman A, Ringh M, et al. Time to Delivery of an Automated External Defibrillator Using a Drone for Simulated Out-of-Hospital Cardiac Arrests vs Emergency Medical Services. *JAMA*. 2017;317(22):2332. doi:10.1001/jama.2017.3957
106. Leung KHB, Grunau B, Al Assil R, et al. Incremental gains in response time with varying base location types for drone-delivered automated external defibrillators. *Resuscitation*. 2022;174:24-30. doi:10.1016/j.resuscitation.2022.03.013
107. Pulver A, Wei R, Mann C. Locating AED enabled medical drones to enhance cardiac arrest response times. *Prehospital Emergency Care*. 2016;20(3):378-389. doi:10.3109/10903127.2015.1115932
108. Schierbeck S, Nord A, Svensson L, et al. National coverage of out-of-hospital cardiac arrests using automated external defibrillator-equipped drones — A geographical information system analysis. *Resuscitation*. 2021;163:136-145. doi:10.1016/j.resuscitation.2021.02.040
109. Schierbeck S, Hollenberg J, Nord A, et al. Automated external defibrillators delivered by drones to patients with suspected out-of-hospital cardiac arrest. *European Heart Journal*. Published online 2021:ehab498. doi:10.1093/eurheartj/ehab498
110. Schierbeck S, Svensson L, Claesson A. Use of a Drone-Delivered Automated External Defibrillator in an Out-of-Hospital Cardiac Arrest. *N Engl J Med*. 2022;386(20):1953-1954. doi:10.1056/NEJMc2200833
111. Berglund E, Hollenberg J, Jonsson M, et al. Effect of Smartphone Dispatch of Volunteer Responders on Automated External Defibrillators and Out-of-Hospital Cardiac Arrests: The SAMBA Randomized Clinical Trial. *JAMA Cardiol*. 2023;8(1):81. doi:10.1001/jamacardio.2022.4362
112. Renkiewicz GK, Hubble MW, Wesley DR, et al. Probability of a Shockable Presenting Rhythm as a Function of EMS Response Time. *Prehospital Emergency Care*. 2014;18(2):224-230. doi:10.3109/10903127.2013.851308