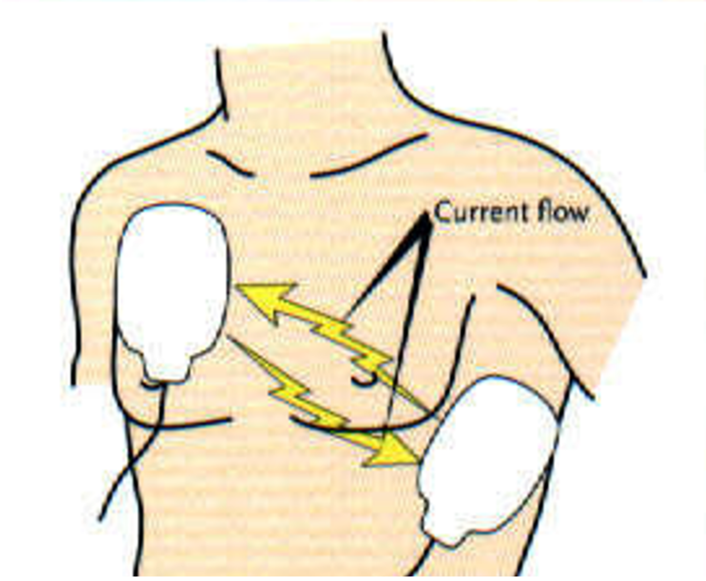
How defibrillators work



The Community Heartbeat Trust

Supporting defibrillation into communities through a governance led, sustainable and resilient manner

How defibrillators work – a non-techy guide

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Defibrillators – magic boxes

There are many defibrillators on the market, at a range of different prices. But why? If they all give a 'shock' why the different prices? Is buying cheap better than paying more? Why is it better to buy 'best' rather than buy 'cheap'?

Defibrillators are like mobile telephones and computers – the more you pay the better the equipment and the more functionality they have. But what does this mean in reality. To understand we have filtered the technical specifications to help you realise that it is worth buying 'best'.

Evolution.

Technology changes over time. Just look at mobile telephones! Since 1990 the mobile telephone has gone from the Nokia 2110, where texting was a real cool invention, to the modern 5G devices that take photos, browse the internet, have video calling and even AI assisted integrated health programmes and diagnoses. The same evolution has happened with defibrillators, with the older designs (still available) have much lower technological abilities than modern designs.

(This visual is a representation of changing technology over time and does not imply any functional or operational differences.)

The first practical defibrillator as we know them appeared in the 1990's, although they are actually much older. These devices were designed for use by a trained medic, and it was assumed the users were trained. Later they evolved to have more detailed audio instructions, but these instructions also assumed the user was trained, and therefore the instructions were more a reminder than anything else. By the 2000's defibrillators were being made available to the public, such that the instructions, still verbal only, where a little more detailed again, but still assumed the user knew what they were doing and required training. Generally, these did not have metronomes. In 2014 the first community designed defibrillators became available, which gave both visual and audio instructions to help the 'untrained' user, and things like metronomes to help with chest compressions rate. Even more modern devices have CPR coaching, and greater range and sensitivities.

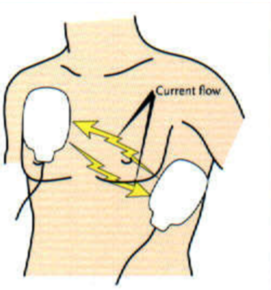
In addition, the sensitivity to the heart rhythms has increased, and the longevity of pads and batteries. The 'shape' of the electrical charge has evolved, with some defibrillators also looking for child vs adult rhythms and adapting accordingly. The transfer of critical medical information is now being made easier by a variety of methods, and devices can be upgraded in the field rather than having to be returned to the manufacturer. Whilst it is still possible to buy the older model devices, that tend to be the cheaper devices on the market, their ability to help in a rescue is less than the more modern devices now available.

What does a defibrillator actually 'do'?

The heart is divided into 4 parts – the upper and lower, and the right and left sides. The upper part of the heart (atria) pumps blood to the lower part of the heart (ventricle) and then the blood is pumped from here to the rest of the body.

The mechanism that makes a heart pump is known as 'depolarisation' of the heart cells. A small 'wave' of electricity passes through the heart, starting at the top right, making the heart cells contract. By doing this the heart overall contracts, and squeezes the blood in the middle of the heart, out and around the body. This is like the release of a coiled spring. So just like a spring, for the heart to work again, the spring needs to be recoiled. This happens in the heart through a process called 're-polarisation' where another small 'wave' of electricity goes through the heart to reset the heart cells to get them ready to work again. About 80ml is pumped with each beat in an adult. This is an equivalent volume to *25,000* cans of coke per day.

When the heart goes into 'fibrillation' it has lost its smooth operation designed to pump blood and oxygen around the body, and the heart is practically no longer pumping. This is critical and without intervention, will lead to death. The heart degrades by 20% per minute in adult humans, once blood flow has stopped, and so time is key.



It was discovered that by applying a very short but powerful electrical charge to the heart, it is possible to reset the heart cells, so they are 'recoiled' and ready to start pumping again. In modern defibrillators, this is achieved by passing this current through the heart in both directions – the first to mimic the heart pumping, and the second to mimic the 'repolarisation'. In technical terms this is called 'Bi-phasic' or two phases. All modern community defibrillators use the 'bi-phasic' approach as less energy can be used to create a more positive outcome.

Defibrillators in the community only work in two situations. **Ventricular fibrillation** (heart is quivering) and also **ventricular tachycardia** (very fast heartbeat).

- Ventricular fibrillation (VF) is where the lower part of the heart is out of sequence and as a result nothing is being pumped out and around the body. This is clearly critical.
- Ventricular tachycardia (VT) is where the lower part of the heart is beating so fast that the heart does not have time to refill, and so almost nothing is being pumped out. It also put a considerable strain on the heart as it is overworking for no result.

Ventricular fibrillation

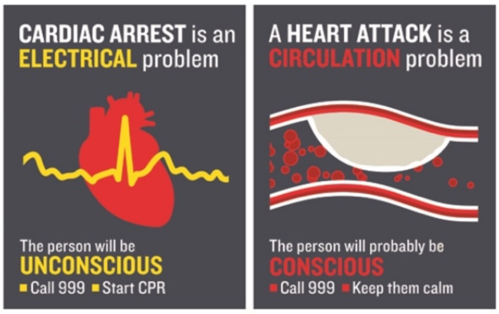
Ventricular tachycardia

In both cases, the defibrillator may give a shock to help rectify these. The defibrillator will not work unless it detects either of these is present, so is very safe to use. You cannot do anything wrong by using a defibrillator. If the above are present, then the patient's life is in danger, and the defibrillator will help save their lives.

A defibrillator shock is not always needed, or giving a shock may not be clinically appropriate. The defibrillator will make this choice, not you. For a defibrillator to 'defibrillate' then fibrillation (vibrating heart) needs to be present. A defibrillator cannot affect any action if fibrillation (or tachycardia) is not present. This means that a defibrillator will not always be successful. The defibrillator actually 'stops' the heart – it is not a 'heart restarter'. If the heart has stopped completely, known as 'asystole', the defibrillator will do nothing.

The difference between a Heart Attack and Cardiac Arrest

Generally, people become confused over the two situations.



A *Heart Attack* is a plumbing problem, where a blood vessel in the heart has become blocked, and as a result no oxygen is getting to parts of the heart beyond the blockage. This results in severe pain in the middle of the chest and radiating down the left arm and into the neck. The patient may be conscious and able to tell you they are in pain. Call 999 Ambulance and keep the patient calm and warm.

A *Cardiac Arrest*, by comparison, is very sudden onset – the space of a heartbeat – and is the result of an electrical problem resulting in the heart stopping pumping. The patient will become unconscious very quickly. As no blood is being pumped, start the chest compressions immediately and call 999 Ambulance. They are not breathing and will change colour.

A 'stroke' is a bleed or blockage in the brain. A defibrillator is not indicated for a Stroke.

Cardiac Arrests are very uncommon in children, defined in defibrillator terms as 7 and under in age, or 25Kg or less. Typically, in an average UK community, statistically, a cardiac arrest will happen in a child once every 3000 years. In defibrillator terms, teenagers are not children, but adults. In adults Cardiac Arrest is more common at a rate of 1 every 1000 adults per annum.

What is meant by 'shock'?

This is the application of a controlled level of electricity to the patient. There are two types of shock – monophasic and biphasic. All modern community defibrillators are biphasic – shocks in both directions.

Within this there are differences in the way the shock is presented, and most defibrillators have a specific 'shape' to the shock being given, with some able to change the parameters surrounding the energy given.

The 'shock' is generally a voltage of around 1000 volts, given for around 10-12 mSec in each phase, and at an amperage resulting in a level of energy given to be in the 150-200 Joules range initially (in community defibrillators). As everyone is different size, shape and level of fat/muscle then everyone has a different 'resistance' so the shock is also changed to match different people's needs and physique. Professional AEDs as used by paramedics have higher energies and manual overrides.

What is meant by 'energy'?

Energy (Joules) = Voltage x Amperage x Time ***Amperage = Voltage / Resistance***

The recommended energy levels for a community defibrillator are from 150J to 360J, with most defibrillators in the community giving 150 – 200J. Some vary the voltage, some the amperage, and some the time the shock is given, to create the energy levels. Beyond 10-12mSec time though the resultant energy is lost due to the heart becoming 'stunned' (Gliner et al. *Circulation.* 1995;92:1634-4). Therefore, most community devices do not go beyond this. Example calculations @ 100 Ohm:

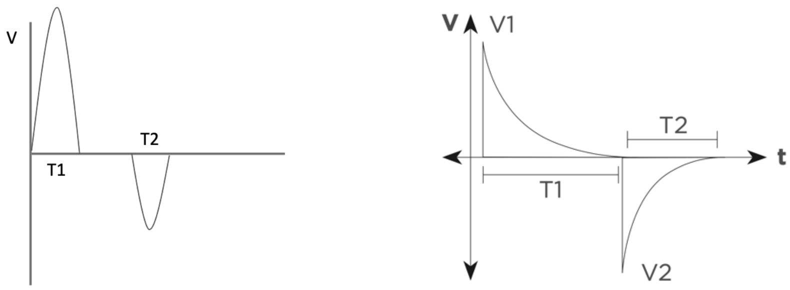
150J = 1000 x 15 x 10mSec ; **200J** = 1000 x15 x 13mSec ; **150**J = 1000 x 8 x 18.75mSec ; **360J** = 1000 x 24 x 15mSec

Some manufactures, such as Zoll, keep their shock time to the optimum 10-12mSec @ 1000v, and vary amperage for example.

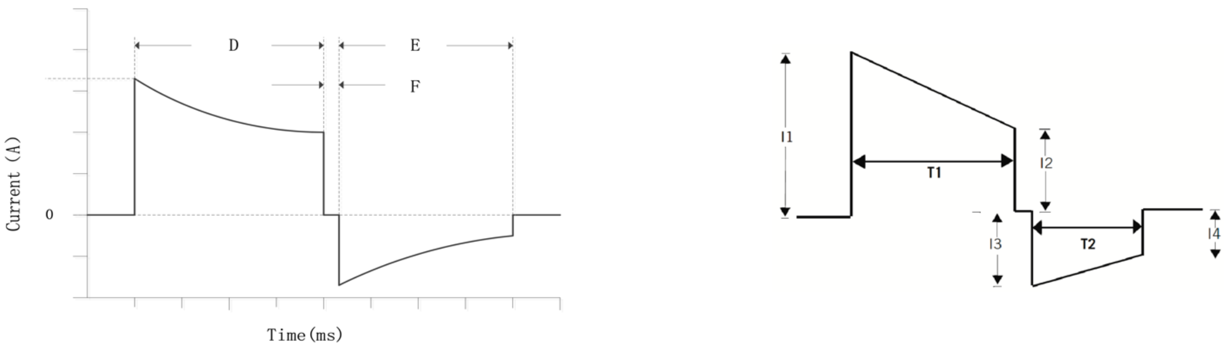
This overall energy can be varied by changes in voltage, time and amperage, or any combination thereof. The more sophisticated the defibrillator, the more it takes into account needs of the patient and body resistance and will vary accordingly. Simple defibrillators, and the older devices, will try to keep their energy fixed at for example 150J.

However, it is also not just about energy, but how this energy is delivered.

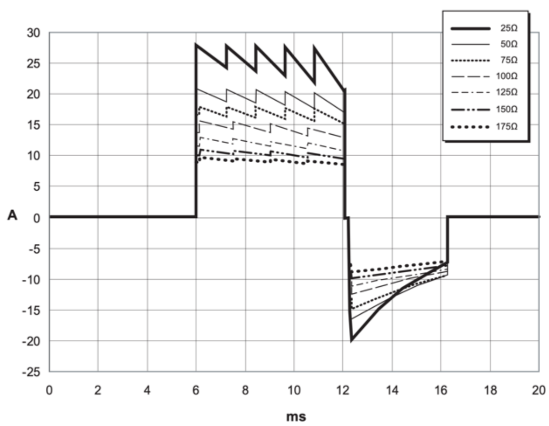
The energy is delivered in 2 phases – biphasic. This means the energy 'wave' is delivered in one direction first, then the reverse direction. The energy is not a straight line, however, as it has been found that to be effective the energy has to be delivered in a format that meets the type of arrythmia. Thus the 'waves' of energy are delivered in shaped bursts. Different defibrillators provide this in different shapes, resulting in different outcomes:



BiPhasic Pulse and BiPhasic Exponential waveforms – simple, or older defibrillator types

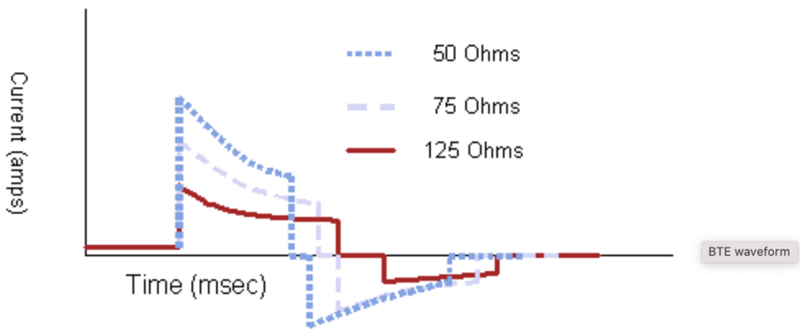


Biphasic Truncated Exponential and Truncated Linear waveforms – majority of community-based defibrillators



Rectilinear Biphasic Waveform – high specification defibrillators eg Zoll.

The actual current delivered can vary by the resistance (size) of the patient, as well as the placement of the pads and adhesion to the skin. Most defibrillators will vary the voltage, current or time to adapt for this. The Stryker series (below visual for CR2) for example varies the time of the shock for reducing amperage/resistance, whereas the Zoll series keeps time and voltage the same but varies the amperage. UK guidance is to always start at around 150J energy (100Ω), not at 360J for example.



What is this in simple everyday language?

Imagine someone asleep. To wake this person up you can:

- Give them a single sharp 'poke' – MonoPhasic
- You can blow in each of their ears – Simplified BiPhasic 'pulse'
- Give them 2 sharp short 'pokes' – one on the left and one on the right – BiPhasic simple exponential
- Give them 2 hard punches/pokes - one on the left and one on the right – BiPhasic truncated exponential
- You can give them a good shake of the shoulders, twice – Rectilinear BiPhasic

Depending upon how deep the sleep is, each of these will have a different outcome, with the latter 'shaking' the most likely to impact and get a result from the greater majority of people. This is how it is with defibrillators. The shape of the curves, and the power of the 'poke' or 'shake' can determine the outcome. Some defibrillators start with a gentle 'poke' and increase the intensity of the 'pokes'. This is called 'escalating energy'.

How is the 'shock' decision derived?

Once the defibrillator has been switched on, and the pads/electrodes connected to the patient's chest, the defibrillator computer will 'analyse' the patient, looking for the tell-tale heart rhythms representing VF and VT. It also measures the resistance of the patient to determine how the energy may need to be varied. The defibrillator will determine if a shock is given, and may choose not to give a shock as at that point in time it is clinically no advantage. At this point it will ask for further chest compressions to be undertaken to give more oxygen to the heart. After 2 minutes it will reassess the situation and then decide again if a shock is required, or clinically beneficial. The defibrillator can carry on doing this many times.

In measuring, different defibrillators have different 'sensitivities' to be able to detect any fibrillation or heart movement. In general, the higher cost machines detect to a lower level of sensitivity, or higher heart rate, and therefore will advise a shock in more cases than those without this level of sensitivity. Generally, VT is considered to be >120 beats per minute at rest (adult) or 160BPM (child). 120BPM in a child could be a normal rate.

For example:

Common defibrillator examples	Sensitivity to VF	Sensitivity to VT (in UK >120 BPM at rest in adult; >160 BPM child)
CR+ (now withdrawn from UK)	200 µV	120 BPM per min (adult only)
Mediana A15	200 µV	160 BPM per min (adult and child)
CellAED (not yet available for the UK – 03/23)	200 µV	130 BPM per minute (adult and child)
Lifepak CR2	200 µV	120 BPM per minute (adult and child)
Lifeline VIEW	200 µV	180 BPM per minute (adult and child)
Zoll AED 3	100 µV	150 BPM (adult mode) and 200 BPM (child mode)

Data from user manuals

Some modern devices have the electronics and software to be able to detect at higher levels of sensitivity, and therefore can shock more frequently than older, or lower sensitivity, devices. Similarly, in children (<=7 or under 25Kg) the devices should adjust for paediatric algorithms, and higher natural heart rates in children. Child attenuation switches only affect energy levels in most devices, by adding additional resistance, and do not adapt to child physiology or heart rate. On this basis the more modern or higher priced defibrillator, the more people that can potentially be rescued and avoid shocks when not needed, particularly in children. Cardiac Arrest is very rare in children. Whilst this may not mean a great deal to the average public, it literally can make a difference between life and death, and the range of rescues, so should be considered.

Other factors influencing whether a shock is advised, or the energy level of the shock given, will be :

- the patient's body mass (ie resistance to electricity)
- the types of arrythmia pattern detected.
- External influence – eg environmental factors may affect the defibrillators ability to offer a solution.
- Defibrillator pads placement and adhesion
- If the patient has no electrical activity in the heart at all, known as 'asystole'

In 2023, the ability of a defibrillator to create a Return of Spontaneous Circulation (RoSC), the measure of a successful rescue using a defibrillator, is around 25% of all cardiac arrests in the community (NHS Ambulance Service statistics). This means 75% will not respond. Communities need to be aware of this. Defibrillators are not 100% successful.

The 3-month survival from hospital is still around 9% though (March 2023).

User interfacing

Most community defibrillators are used by untrained rescuers. Whilst training is always recommended, these devices are so safe to use that it is considered that they should be allowed to be used even if the rescuer is not trained. Current statements on the training requirement are confusing and often contradictory. Yes, you can use a defibrillator with no training – you can drive a car with no training – but training not only builds confidence and addresses concerns, but also tells you what to look for both pre and post use of the defibrillator. Training is also required so people know what to look for to determine an SCA, so the equipment is not misused, and how to undertake chest compressions correctly. Also, what to look for if the shock that is delivered is successful. To say training is 'not required' is misleading. Most manufacturers will state that training is required, although some local variation on this may exist where agreed with the regulatory authorities (3 typical current examples):

WARNING

- **This equipment must be operated by persons who have been trained in its operation. The operator should be trained in basic life support, advanced cardiac life support or other emergency medical response.**

The devices are intended for use by personnel who have been trained in their operation.

The CellAED® is intended for use by minimally trained individuals (who have undergone training in the use of the CellAED®) to treat patients of suspected sudden cardiac arrest (SCA).

How the defibrillator talks to the rescuer, what it says, voice prompts, voice intonation, phraseology, language, visualising – static or dynamic/video – whether it can be used by all members of the public (adherence to Equalities legislation), all play a part in the choice of equipment. A recent AED in the UK gave detailed instructions, but the intonation, emphasis of voice, accent, all gave the untrained lay rescuer a feeling of 'panic' when trying to use. So, voice instructions alone are not the only consideration.

Voice prompts have been the mainstay of instructions for AEDs for many years. However, the type of instructions and the content of these instructions has changed over the years. Older devices dating from the early 2000's and before (eg. CR+, G3, etc) have fewer instructions than more modern devices (eg. VIEW, Zoll 3, etc) as they were designed to be used by the trained user, and assumed a trained user just needed reminders, not full instruction sets.

Visual displays now play an important part of modern devices and help make the device EQ2010 compliant. You do not know who will be using a public device and so adherence to EQ2010 becomes important, as the user will be stressed and panicking, may be in a noisy environment, may have hearing issues, may not speak English or may be a child using. All of these are overcome by the use of visualised instruction sets, along with the audio. Visualised instructions also allow for the defibrillator to have a limited range of built in training assistance for the untrained rescuer.

Some modern devices will also have CPR *coaching*. In the early defibrillators there was no CPR support. Later on, a metronome was added, and this was considered at the time to be a major advance. Modern devices now have the CPR coaching, where the quality of CPR is monitored and positive reinforcement feedback given – "push harder" – "go faster" – " you're doing great!" – etc. It is claimed by some manufactures that this increases positive outcomes by as much as 30%.

Transferring of clinical data

The defibrillator forms part of the clinical treatment of a patient. As part of this it is normally essential for this data to be transferred to the hospital to be part of the clinical record of the treatment of the patient.

Older devices required this equipment to be taken away by the ambulance service or local servicing agent to be able to download through a direct or IrDA link to a computer and then send this off. More modern devices use either an SD card or USB to enable the transfer of the data, and some offer WiFi or 4G to be able to make the transfer. It is important for the community to be ICO registered as they are handling clinical data. However, most communities will not know where to send the clinical data, and so some devices also have the ability to be supported by outside agents such as CHT, who can facilitate the transfer for you. There are also devices to assist with this such as RescueWrist®, as wrist-band USB drive that has the download software and the reading software included.

RESCUE WRIST

Again, the ease of transfer of clinical data should be at the forefront of choice of equipment.

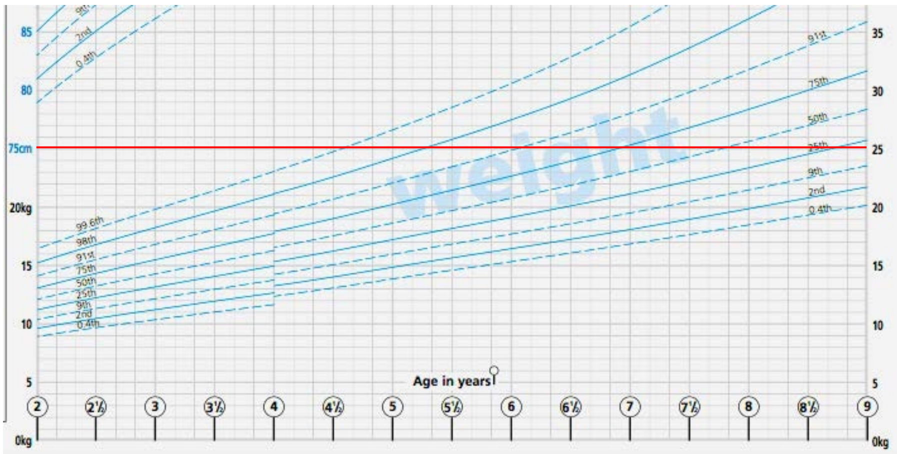
Children

Cardiac Arrest in children – a ‘child’ is defined as 7 and under or under 25Kg - is very rare; typically once every 3000 years in an average UK community. Thus, the facility for child ‘switches’ should not influence any decision on choice of equipment, unless an absolute clinical need has been established. If there is a child at risk, then the child will probably have their own device anyway. The risk with child ‘switches’ is they are misused, or used inappropriately, or left in paediatric mode and used on an adult, with the result that the coroner would determine the equipment may have been misused, resulting in a failed rescue. They certainly add to the confusion in a rescue, and as such can cause more problems than they solve. Avoid child ‘switches’ in community devices unless they are self-resetting to adult, or better, the defibrillator is designed with paediatric algorithms. At time of writing, there is only one device available for public community use with paediatric algorithms – the Zoll AED 3. Note - recent clinical evidence suggests only 1 in 6 SCA in children of 7 and under will respond to a shock/AED.

Vital Signs in Children

Heart Rate (rate/min)		
Age	**Awake Rate**	**Sleeping Rate**
Newborn to 3 months	85 to 205	80 to 160
3 months to 2 years	100 to 190	75 to 160
2 to 10 years	60 to 140	60 to 90
>10 years	60 to 100	50 to 90

Height/Weight chart for the UK Department of Health:



“If there is any possibility that an AED may need to be used in children, the purchaser should check that the performance of the particular model has been tested in paediatric arrhythmias.” – RC(UK) 2015

Fully-Auto or semi-Auto?

Either – your choice. Semi-auto gives better control and safety, particularly when untrained users are involved.

A **fully auto** defibrillator will assess the patient, make a decision to shock and generally give you around 3 seconds to stand clear before automatically giving the shock. A **semi-automatic** defibrillator will assess the patient, advise shock, but allow you the user to press the button to deliver the shock. Things are under your control. In a community setting, you do not know what other incidents may happen, or forget to ask others to ‘stand clear’. Hence a semi-auto is generally considered better for the untrained user. The shock delivered and all other parameters are the same between both routes.

What if the defibrillator "does not work"?

All defibrillators in the community must meet a certain standard. This includes an inbuilt decision whether a shock would be given or not, based upon the protocols stored within the defibrillator itself. There is no possibility for anyone to alter this process, even an attending nurse, paramedic or doctor.

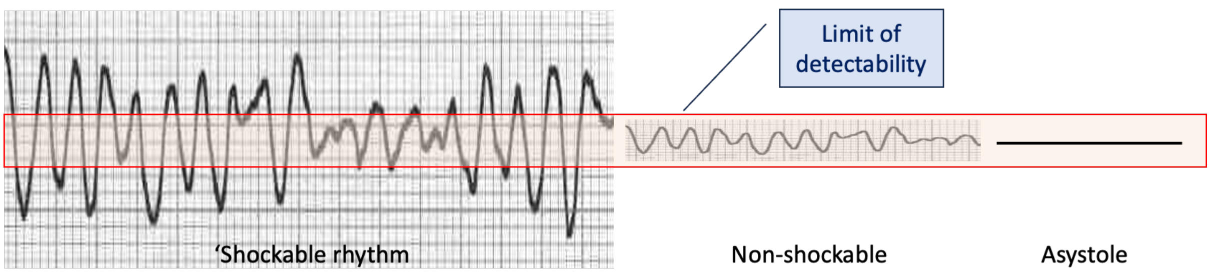
The defibrillator looks for a shockable rhythm, and if one is found, it will advise a shock if this is clinically beneficial. It will then review this 2 minutes later, and advise if another shock is required or not. In between times, it will advise chest compressions be undertaken to pump oxygen around the body, and to keep the heart alive.

It will then wait another 2 minutes and repeat, and so on.

If at any time the rhythms stop being 'shockable' the device will advise 'no shock advised' and will not allow a shock to be given. It will again reassess every 2 minutes.

What do we mean by 'shockable'?

When the heart is in fibrillation, as it is being starved of oxygen, it is slowly dying, by about 20% per minute. This means the signals that can be detected are getting 'quieter'. Once these signals fall below a certain level, depending upon the AED being used, the signal becomes undetectable. If this happens, the defibrillator will advise 'no shock'. More advanced and modern defibrillators are more sensitive and can detect at lower levels of 'signal', and therefore work in a wider range of situations.



There are several reasons 'no shock advised' may happen, including:

1. At one extreme, the patient was recovering (or not in Cardiac Arrest) and so no shocks were required as the device had decided it was not clinically appropriate.
2. At the other end of the spectrum, the patient had deteriorated sufficiently that there was no longer any shockable rhythm detected by the device.

Unlike professional devices, which have much higher sensitivities, community devices only work within certain sensitivities, and in a community whether a shockable rhythm can be detected will depend upon things such as :

- time lapse before CPR was started;
- time to first shock;
- clinical condition of the patient that caused the SCA (eg Heart Attack);
- ambient weather (hot days make shocks less effective than cold days for example);
- underlying cause of the cardiac arrest – for example if due to a heart attack, it maybe the heart continues to degrade due to the blockage.
- Concurrent co-morbidities.

At best, in the UK, NHS statistics state that only 25% of patients in the community survive to hospital (ie 75% of the time the patient does not recover). Survival from hospital is currently around 9% (May 2023).

If a patient is deteriorating during the rescue, the community AED will stop advising a shock when it was no longer able to detect any shockable rhythm, and therefore the shock would not have any beneficial clinical result.

Community defibrillation is about giving people a chance to survive, that they would not otherwise have. It is not 100% successful. Communities must realise that not every 999 call requires a defibrillator, and when required, it is only successful in 25% of rescues on average. In children (defined as 7 and under) Cardiac Arrest is very rare, but when this occurs, only 1 in 6 cardiac arrests are 'shockable' by a community defibrillator.

It is always worth investing in the highest specification equipment. Cheap and older equipment tends not to be as sensitive, be older technology, and also often lacks other features for community use, such as CPR coaching and visual displays.

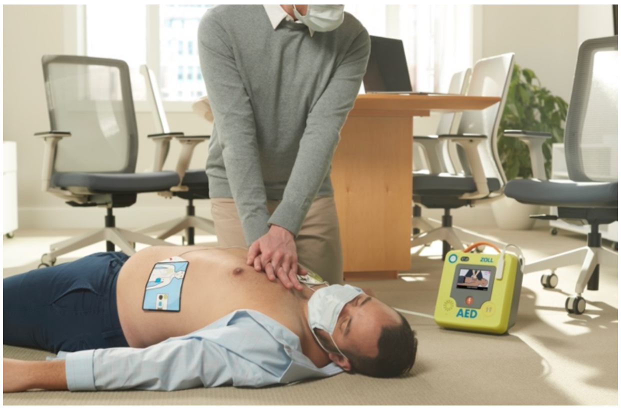
Signage

The Health and Safety Signs and Signals regulations suggest that correct signage should be used for any First Aid location, including defibrillators. There should be one sign above the location, visible from at least 50m away, and at least 2 others giving directions to the defibrillator placed around in the community. There is only one internationally recognisable sign for use in the UK. This is the ILCOR defibrillator signage. Like road, fire, and other emergency signs, it is important people recognise the correct signage wherever they go in the world, or where visitors from overseas are present (airports, tourist venues, travel, etc).

Don't confuse people by using the wrong, or confusing, signage. Time is key.

What does this all mean to the average person?

Like mobile telephones, there are many defibrillators available. They all give a 'shock'. But they all have differences which do impact on their suitability for different tasks or situations. Trying to choose as a lay person is a difficult exercise.



The features of a defibrillator will alter the price and ability as to what the equipment can do, how it is maintained, how data is transferred, how the interface helps the rescuer, and the type and force of the 'shock'. Which defibrillator is right for a given community, office, sports club will in some way depend upon need. But the general rule is go for the highest specification you can afford, whilst also taking into account the usability features to make sure you do not open yourself to liabilities.

Work with experts in this area who can give you objective and direct advice, and who can also offer extended service which you will need. Generally, this excludes internet providers, or those offering 'too good to be true' offers of 'grants' etc. Things are 'cheap' for a reason. Avoid older model equipment, or equipment that is not supported by extensive clinical evidence, or certifications (eg FDA, MDR). Think about who will be using this and be sensitive to their needs for ease of use in a stressful situation. Consider practical issues such as robustness, temperature resilience, support and maintenance issues, and ongoing long-term costs. Does the supplier have a service and support offering in the UK?

Above all, don't forget training. Successful rescues are all about education. It is important and essential both for confidence and good governance that an education programme is included in any project. Training is not a video, but a planned session given by someone qualified. Training is important to set expectations and build confidence. It also helps avoid PTSD situations. Have you considered access to trained counsellors?

Remember – not every patient collapse requires a defibrillator to be used. Call 999 ambulance and take their advice. Similarly, where a defibrillator is required, not every situation will the defibrillator help. Do not assume that using a defibrillator will always result in a successful rescue.

The 'best' defibrillator is the one that arrives fastest to the patient, regardless of features.

You can only try your best, and give someone a chance to live!

Community Heartbeat Trust charity (updated 07/2023)