On the essence of cardiopulmonary resuscitation [version 1; peer review: awaiting peer review]

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Abstract
This article discusses that the essence of cardiopulmonary resuscitation (CPR) is energy transfer. The concept of occult cardiac arrest is proposed, and cardioversion after cardiac arrest is divided into spontaneous cardioversion and CPR according to the principle of energy transfer: the internal energy transmission of the body makes the cardioversion that is known as spontaneous cardioversion, and energy is mainly transfers from the outside leads to cardioversion, that is, CPR. The concept of domain energy in CPR is proposed, and it is argued that only energy transfer beyond the domain energy can lead to cardioversion in both spontaneous cardioversion and CPR. The principle of energy transfer is used to explain the common clinical electrocardiographic phenomena: dysrhythmia can occur when the energy required for the cardiac functions is insufficient, it is a manifestation of self-protection of the heart and the body, and the mechanism is further argued. It is demonstrated that serious cardiac events, such as ventricular fibrillation and cardiac arrest, are special types of cardiac self-protection. The mechanisms, general rules, and energy properties of modern CPR energy transfer are described, and the influence and interaction of energy transfer principle on the three states of time, space, and energy transfer during CPR are assessed, which will be significant for future research on CPR.

Keywords
cardioversion; cardiopulmonary resuscitation; energy transfer; domain energy; three states
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Cardiac arrest (CA) is an important global public health challenge. Although some patients receive cardiopulmonary resuscitation (CPR), the survival rate at discharge with a promising neurological function is still low,1–3 and there is an urgent need to study the theory and methods of CPR.

The study was approved by the Ethics Committee of Lu’an Civily Hospital (the Ethics report approval number: 2021-04-023). There is no relevant informed consent for this work.

1. The concept of CA and the essence of CPR
1.1 The concept of CA and its extension
The concept of CA in modern medicine is the sudden cessation of cardiac pumping function.4 The concept of CA can be extended as a group of syndromes with a short asystole time and no obvious clinical manifestations, accompanied by actual pathophysiological changes in the body, which is called occult CA. As a result, CA includes a larger group of cardiac emergencies with different pathophysiological or clinical manifestations depending on the duration of asystole, which can be divided into two types: ordinary CA (clinical manifestations and pathophysiological changes) and occult CA (with no or mild clinical manifestations and some pathophysiological changes).

1.2 The essence of CPR
After CA, the patient’s body is depleted due to the gradual transfer of energy (bioenergy, kinetic energy, thermal energy, electrical energy, etc.) to the external environment over time, and the longer the asystole time, the more energy is lost from the body.

If the heart is to be re-paced, sufficient energy must be delivered to the heart. Cardiac resuscitation can be defined as the process of energy transfer and utilization. Depending on the type of CA (as mentioned above) and the different ways of energy transfer, cardiac resuscitation is divided into cardiac self-resuscitation and artificial resuscitation (i.e., CPR).

Cardiac self-resuscitation relies on the body’s energy transfer to the heart, making the heart cardioversion or re-pacing (hereinafter, cardioversion is used, rather than all forms of heart rhythm after re-pacing). CPR is the transfer of external energy to the body, which then transfers it to the heart and leads the heart to cardioversion. Excluding other influential factors, if energy transfer is effective, the heart is able to undergo cardioversion, and cardiac self-resuscitation or CPR is effective.

Therefore, whether it is cardiac self-resuscitation or CPR, the essence is energy transfer.

2. Cardiac self-resuscitation—transfer of energy from the body
2.1 Spontaneous cardioversion and resuscitation
Regardless of the type of CA, cardiac resuscitation is achieved in some patients by spontaneous cardioversion. This includes pure spontaneous cardioversion and the Lazarus phenomenon.5 The Lazarus phenomenon confirms the objective of spontaneous cardioversion/resuscitation.

Whether the cause of CA is ventricular fibrillation, ventricular tachycardia, or ventricular arrest, when the heart is under the status of cardioversion, the first heartbeat that appears, the first QRS wave group on the electrocardiogram, such as after ventricular fibrillation, appears to be the automatic depolarization of a pacing point and eventually depolarizes the heart, while the essence is energy transfer. Without energy transfer, there would be no automatic depolarization of the pacing point, accompanying by less self-cardioversion after several minutes of asystole.6 This energy is generated by the body during asystole and transmitted to the heart, and with the intervention of energy regulation mechanisms, it selectively acts on a specific area of the heart, such as a pacing point, rather than the whole heart, in order to depolarize the pacing point, eventually manifesting as the first cardiac depolarization after asystole. Thus, limited energy is used rationally and efficiently to successfully complete cardioversion/resuscitation.

Energy is the driving force behind cardioversion, which originates from the body and restarts the heart in form of cardiac depolarization. During this time, the body, especially the heart, undergoes a series of electrophysiological and pathophysiological changes, whereas the essence is the change of energy and energy transfer.

The process of cardioversion or re-pacing by heart using energy is called cardiac self-resuscitation.

Without energy transmission, the heart will not be able to undergo cardioversion. The Lazarus phenomenon is not only a consequence of energy transfer, but also further proves that energy transfer is the only driving force for cardioversion.
2.2 The concept of “domain energy”
When the heart stops, how much energy is stored in the body for cardioversion of the heart through internal transmission? The authors proposed the concept of “critical energy or domain energy (hereinafter referred to “domain energy”): the domain energy is the minimum amount of energy that the body can survive on, which is greater than the energy that the body can survive, and less than the energy that the body rapidly declines.

In an emergency, the body can supply the heart with special energy production (energy production of non-lethal organs, such as muscle or visceral organs) and energy transfer to maintain the cardiac function. The sum of the energy produced and the energy present in the body must exceed the domain energy for the heart to have enough energy to cardioversion. Presumably, the Adams–Stokes (cardio-cerebral ischemia) syndrome or the generalized convulsions during a grand mal seizure are examples that the body mobilizes the muscles of the whole body to generate energy to supply important organs (e.g., heart and brain).

2.3 Self-protection mechanism of the heart
As the body is associated with a large number of self-protection mechanisms, the heart itself has self-protection mechanisms. It can protect the body and perpetuate life through multiple forms of energy transfer from primary to advanced levels, including the heart itself, from the body to the heart, and by mobilizing energy transfer from tissues and organs throughout the body to the heart.

Escape beats and escaped rhythms are self-protective phenomena of the heart, and ventricular tachycardia or ventricular fibrillation may also be a self-protective measure of the heart. When an emergency event that endangers the cardiac function occurs, the energy required for a normal cardiac function is seriously insufficient and can induce CA, and the heart extends the myocardium contract in form of ventricular tachycardia or ventricular fibrillation. At the same time, the body also participates in the productivity (such as Adams–Stokes syndrome) and, when the generated energy is greater than the domain energy, cardioversion may occur.

Ventricular fibrillation is therefore a self-protective measure, resulting from the activation of protective mechanisms by the heart after CA. Ventricular fibrillation is not the cause of CA, and it is a self-protective electrophysiological and mechanical response triggered after CA.

Several other severe dysrhythmias, such as sinus arrest, ventricular arrest, and pulseless electrical activity are associated with the occurrence of CA, while they, similar to ventricular fibrillation, are a consequence rather than a cause of CA and are electrophysiological manifestations after CA.

After CA, the heart can pace itself if the heart/body passes its own energy production and exceeds the domain energy; when the heart/body’s own energy is lower than the domain energy, it cannot start its own self-rescue mechanism, and it needs an external energy transfer to make the heart possible to pace again, such as CPR, ICD, pacemaker, etc.

Ventricular fibrillation is a protective mechanism triggered by heart and generates energy; when the energy produced is greater than the domain energy, the heart can automatically implement cardioversion. Numerous other dysrhythmias after CA suggested that the heart does not have enough energy to start ventricular fibrillation to generate energy, while it can only rely on the body to generate energy (e.g., Adams–Stokes syndrome) or other currently undiscovered forms of energy production in the heart, or the protection of external energy, whereas they are also embodiment of cardiac self-protection. The difference between them and ventricular fibrillation lies in the energy difference in CA. The greater the energy, the greater the possibility of cardioversion.

Consequently, it seems that all dysrhythmias are manifestations of cardiac self-protection mechanisms after CA.

2.4 Cardiac self-regulatory–resting–resuscitation mechanism
From the point of view of mechanical movement, the heart is undoubtedly the organ with a large amount of body movement. Due to the regulation of nerves and body fluids, the body can ensure the degree of relaxation of the heart by adjusting myocardial tension, arteriovenous tension, and even heart rate within a certain range. However, when the physiological range is exceeded, the heart needs to rest for a period of time to restore energy reserves and myocardial function. dysrhythmias may be a form of cardiac resting, a reflection of self-protection mechanism. There are two types of dysrhythmias: slow dysrhythmias and compensatory intervals of tachydysrhythmias are ways in which the heart regulates rest; tachydysrhythmias, including tachycardia, heart flutter, and fibrillation are the need for the heart to generate energy, which are more urgent than the first type, suggesting that the heart is also not physiologically in a resting state. When the energy produced by heart exceeds the domain energy, tachydysrhythmia will be recovered, otherwise, dysrhythmia will
be further deteriorated. Ventricular flutter and ventricular fibrillation suggest that the heart is in severe energy failure and needs to produce more energy.

Compared with a normal heart, the pathological heart requires more rest and is more prone to CA. It is inferred that, similar to dysrhythmias, CA is a manifestation of the self-regulatory mechanism of the heart, which essentially regulates the cardiac resting and the gathering of energy to restart it.

These cardiac functions can be summarized as the cardiac self-regulatory–resting–resuscitation mechanism.

2.5 Forms of energy in asystole
The electrocardiogram (EKG) at the time of the patient’s moribund death is a special form of energy in asystole with a straight EKG and very few ventricular fibrillation waves. The main reason for this is that the energy of the moribund body has been severely attenuated, which is markedly lower than the domain energy, and both the body and the heart have no energy transfer and initiate self-rescue mechanisms; thus, no ventricular fibrillation occurs or mild ventricular fibrillation with almost no vital information can be found.

However, there are several special circumstances that suggest the presence of energy in the body or heart: (1) sinus arrest or sinus quiescence in sick sinus syndrome mainly has a long interval when there is no pacing; (2) a linear EKG between defibrillation and rhythm recovery in patients with ventricular fibrillation; (3) the Lazarus phenomenon; (4) a proportion of patients with successful CPR who have a linear EKG during resuscitation or may change from a non-shockable to a shockable heart rhythm.11–13

2.6 Summary
CA or asystole is the result and expression of the primary force of cardiac functions (i.e., cardiac energy depletion, and cardioversion or re-pacing), requires a new energy transfer.

The cardiac self-resuscitation mechanism can be summarized as follows: body energy is transferred to the heart, the pacing point, the conduction system and myocardium are successively depolarized, and the cardioversion is finally performed.

When the body energy is greater than the domain energy, the next stage of physiological function is completed by the energy transfer from the previous stage; when the body energy is less than the domain energy, within a certain range, the body can start the self-protection mechanism to generate energy and transmit it to the heart for cardioversion.

The essence of cardiac cardioversion and resuscitation is energy transmission.

3. CPR (the transfer of external energy of the body)
3.1 The pathways of external energy transfer
When the asystole is prolonged and its own energy decays below the domain energy,14 the body cannot perform cardioversion by its own energy transfer, and when the energy decays to a lower degree, the body shows an irreversible tendency to decay. At this time, external energy will become the key to saving life.

There are several relationships between external energy transfer to the body and the body’s own energy: first, the sum of external energy and the body’s own energy is greater than the domain energy; second, the more the body’s energy decays, the more the external energy transfer is required; third, when the body’s own energy decays to a certain level, no matter how much external energy there is, cardioversion cannot be performed.

Modern CPR techniques, such as chest compressions, artificial respiration, and electroshock defibrillation all deliver energy to the body. The magnitude, essence, and mode of energy transfer are unique: chest compressions (kinetic and biological energy), artificial respiration (biological and kinetic energy), and electroshock defibrillation (electrical energy). The common precordial tapping in CPR was previously a type of kinetic energy transmission.

3.2 The principle of CPR energy transfer
3.2.1 Defibrillation by electric shock (transmission of electrical energy)
As electroshock defibrillation is the direct transfer of electrical energy to the body, it theoretically seems to be more in line with the energy transfer principle, whereas the electrical energy transferred to the body is not directly utilized, and it requires the involvement of the energy conversion mechanisms of the body to regulate it.
However, the energy form of defibrillation is not only electrical energy, but also kinetic energy can sometimes achieve the purpose of defibrillation or cardioversion, such as precordial percussion and chest compressions. Therefore, defibrillation or cardioversion is only a phenomenon, and their essence is the transfer and effect of energy.

As defibrillation by electric shock is only a form of energy transfer and substitution (ventricular fibrillation itself can also generate energy) and is influenced by several factors, the energy received by the body after electric shock must be greater than the energy produced by ventricular fibrillation. Thus, defibrillation will not be fully effective, or even if it is effective, it may not be able to bring the heart back into rhythm. The energy transfer principle can be analyzed as follows: first, at the same ventricular fibrillation, coarse fibrillation suggests that the body or the heart has more energy than fine fibrillation, which is lower than, while it is close to the domain energy, and the external transfer of a less amount of energy can effectively defibrillate the heart, and even a percussion to the precordial area may defibrillate the heart, while fine fibrillation is the opposite;15,16 second, the shorter the defibrillation interval, the closer the energy gathered by the body is to the domain energy, and the better the defibrillation effect;17 third, defibrillation is effective, whereas the sum of the energy provided by defibrillation and the body’s own energy does not exceed the domain energy, therefore, the cardioversion cannot be performed; fourth, early defibrillation is better,18 the longer the asystole time, the more the body energy decays, and the defibrillation effect is always getting worse no matter how much electrical energy is used.

Ventricular fibrillation and defibrillation are not contradictory, and they are both forms of energy production or energy transfer: ventricular fibrillation is the form of the body’s own energy production, and defibrillation is the form of external energy transfer, which is an important complement to ventricular fibrillation to generate energy.

3.2.2 Chest compressions and artificial respiration (kinetic energy and bioenergy transfer)

Chest compressions include the direct transfer of kinetic energy to the body, which is the driving force of modern CPR mechanisms, such as the so-called “heart pump” and “chest pump”, promoting blood flow and cardioversion in the heart and aorta. Early chest compressions can even make ATP of myocardial fibers to reach the level before asystole,14 while cardioversion can be still performed with difficulties at this time. Cardioversion is possible only when the amplitude and frequency of the compression reach a certain degree, and the energy transferred to the body and heart continuously increases and exceeds the domain energy.

Bioenergy is the most basic energy of the body and heart. For instance, in cases of in-hospital CA in COVID-19, the main clinical manifestations are asystole and pulseless electrical activity, while very few exhibit a shockable rhythm.19,20 This phenomenon suggests that severe hypoxia indicates a lack of bioenergy in the body and heart, which is the basis for the action of other forms of energy. Secondly, the biological energy of the body is consumed due to severe hypoxia, while the cardiac energy originates from the body. At this time, the heart has no energy for cardioversion even the heart itself is not seriously damaged.

Artificial ventilation delivers oxygen and other substances that are required for the body and energy metabolism; therefore, oxygen and other substances carry the bioenergy transfer of artificial ventilation. A growing body of evidence proved that the success rate of CPR with artificial ventilation alone is very low, or the simple transmission of bioenergy can rarely lead to cardioversion, which may be related to the high requirements for the utilization of bioenergy.

Although it is not still possible to precisely measure the energy delivered to the body by chest compressions and artificial ventilation, after more than half a century of practice, the main parameters of these two techniques, such as depth, frequency, duration of chest compressions,21 respiratory rate, time per ventilation, and ventilation volume, have been repeatedly studied and revised to explore the most appropriate energy properties and energy transfer methods.

3.2.3 Summary

The essence of modern CPR is energy transmission of various properties. Unassisted chest compressions, mechanical CPR,22 electroconvulsive defibrillation, and manual ventilation can all generate and deliver energy to the heart in pathways that are difficult to achieve with the drug therapy alone.23 The heart seems to be more receptive to kinetic and electrical energy, as well as to biological energy, which requires to be performed under specific conditions. It is hypothesized that if the pathway is correct, the heart can receive any form of externally transmitted energy, while it must be converted into an energy property that the heart can utilize through an energy conversion mechanism within the body.
4. Three states of CPR (time, space, and energy transfer)

Time, space, and energy transfer are the three states of CPR. These three states are interdependent and interact with each other: time and energy transfer throughout the space of CPR, space and energy transfer exist in any time period of CPR, and there is always energy and energy transfer in any time and space, including CPR. Their interactions can be summarized as follows: time–space–energy–time, and time–space–energy, space and energy–time, energy and time–space, and time–space–energy interactions, forming complex and mutually integrated mechanisms of action.29

Modern CPR and the possible future creation of novel CPR theories and practices based on the principle of energy transfer will be inseparable from these three states.

Data availability
No data are associated with this article.

References

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