**ECG Characteristics as Indicators of The Aetiology of Pulseless Electrical Activity:**

**A Systematic Review**

**ABSTRACT**

**Background**

The incidence of pulseless electrical activity (PEA) as a presenting rhythm in out-of-hospital cardiac arrest is rising in comparison to other rhythms. Prompt recognition of the cause of PEA can improve outcomes. The assessment of electrocardiogram [ECG] characteristics during resuscitation has been suggested as a source of diagnostic information for clinicians.

The aim of this systematic review was to identify literature evaluating the use of ECG characteristics as indicators of the aetiology of PEA, and to consider how their findings may be utilised in clinical practice.

**Methods**

Case series, observational studies, randomised controlled trials and empirical research investigating the ECG characteristics of adult patients and reporting the aetiology of PEA were searched for via a systematic literature search of the MEDLINE, CINAHL Plus and EMBASE databases. Searches for grey literature, and reference screening were also performed. A risk of bias assessment was performed for each included study.

**Results**

A total of four articles were selected for final inclusion. One study reported a statistically significant correlation between the presence of wide QRS complexes and hyperkalaemia. No further associations between ECG characteristics and the aetiology of cardiac arrest were reported. Three studies were found to be at moderate risk of bias due to incomplete inclusion of patients. Studies often assessed groups of aetiologies, rather than specific causes. Consequently, this limits their application in clinical practice.

**Conclusion**

ECG characteristics should not be used in isolation as an indicator of the aetiology of cardiac arrest in patients with PEA. The included studies often employed broad categorisations of aetiologies, limiting their ability to identify specific characteristics associated with individual causes.

Future research should include analysis of specific aetiologies and the evaluation of ECG characteristics to augment other diagnostic tools.

**INTRODUCTION**

 Cardiac arrest is a complex condition and a significant cause of mortality and healthcare resource utilisation globally (Graham, McCoy and Schultz, 2015; Geri *et al.*, 2020). Many initiatives aimed at improving survival from cardiac arrest have focused upon the care of patients presenting with shockable rhythms. However, the incidence of shockable presenting rhythms in out-of-hospital cardiac arrest [OHCA] has been reported to be decreasing (Keller and Halperin, 2015). Conversely, as identified by Bergstrom *et al.* (2018), the incidence of patients with pulseless electrical activity (PEA) is increasing. This retrospective database audit of 48,707 patients with OHCA revealed the incidence of PEA as a presenting rhythm increased in every five year period between 1990 and 2016 (p < 0.0001).

 Identifying the underlying cause of PEA during resuscitation is crucial for delivering appropriate interventions and improving patient outcomes (Bergum *et al.*, 2015; Dewolf *et al.*, 2022). However, the accurate identification of the precipitating aetiology is difficult for clinicians as PEA is a complex clinical state with several subtypes, caused by a wide spectrum of aetiologies (Aufderheide, 2007). The evaluation of ECG characteristics during resuscitation from PEA may aid with identification of the cause and required interventions. A case series and narrative review by Mehta and Brady (2012) proposed that QRS width may differ between metabolic and mechanical aetiologies. This theory has since been adapted into an algorithmic approach by Littman, Bustin and Haley (2014), who advocated using the width of QRS complexes to determine the cause of PEA and then deliver subsequent treatments by using this in combination with clinical findings. This use of ECG characteristics to aid with identifying the cause of OHCA in patients with PEA is included within the Joint Royal Colleges Ambulance Liaison Committee (JRCALC) guidelines for ALS (JRCALC, 2022). Whilst these are theoretical models based upon small case series and expert opinion of the physiological responses seen to various conditions, the ability of ECG characteristics to identify precipitating aetiologies has not been clinically validated. Therefore, it has not been established whether these may offer accurate diagnostic insight when assessed during cardiac arrest.

 A scoping search and review of the PROSPERO registry found no previous systematic reviews have been undertaken on the relationship between ECG characteristics and PEA aetiology. Van den Bempt, Wauters and Dewolf (2021) undertook a systematic literature search of prehospital identification of the causes of PEA, however this only included two studies focusing upon ECG characteristics and did not critically appraise their findings. Furthermore, this review only included studies undertaken in the prehospital environment. Coppola *et al*. (2021) conducted a systematic review on the management of PEA by UK ambulance services. This reported a consensus on the lack of available evidence on the management of PEA. The authors of this review reiterated that the early recognition and appropriate treatment of reversible causes may improve survival, but concluded this is currently challenging to achieve and further evidence is needed to inform guidelines.

**AIM**

The aim of this systematic review is to identify and critically appraise literature evaluating the use of ECG characteristics as indicators of the aetiology of PEA, and to consider how their findings may be utilised in clinical practice.

**METHODS**

 The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were used to structure this review (Page *et al.*, 2021a).

 Inclusion and exclusion criteria were determined by discussion between both authors. The criteria used are displayed within Table 1. A systematic literature search of the MEDLINE and CINAHL Plus databases was performed using the EBSCOhost platform. EMBASE was searched using the Ovid platform. These searches were performed between 22nd July 2023 and 31st July 2023. Search terms were determined by evaluating known articles on the subject and were piloted using selected databases. See Table 2 for the search terms used for EMBASE. Boolean operators were used to combine search terms. The full search strategies are contained within Appendices A and B.

|  |  |
| --- | --- |
| **Inclusion** | **Exclusion** |
| Case series, observational studies, randomised controlled trials, and empirical research published in peer-reviewed scientific journals with full-text availability | Single-patient case reports, neonatal or paediatric studies, animal studies |
| Published after 1st January 2013 | Studies reporting non-standard ECG measurements  |
| English language | Studies describing the effects of medications, electrical, or mechanical cardiac support during resuscitation |
| describing ECG characteristics recorded in adult patients during episodes of PEA and assessed their relationship with the aetiology of cardiac arrest |  |
| Table 1: Inclusion and exclusion criteria **EMBASE search terms** |
| tachy\* OR brady\* OR rate OR complex\* OR wide OR narrow OR QRS OR ‘p wave’ OR ’t wave’ OR activity OR ECG OR EKG OR electrocard\* |
| PEA OR EMD OR ‘electromechanical dissociation’ OR ‘pulseless electrical activity’ |
| aetiolog\* OR etiolog\* OR cause\* OR diagnos\* OR condition\* OR associat\* |
| 'narrow QRS' OR 'narrow complex' OR 'wide QRS' OR 'wide complex' |
| 'ECG characteristics' OR components |
| metabolic OR mechanical |
| hyper\* OR hypo\* |

Table 2. Search terms used for EMBASE.

 Search results were electronically exported into Refworks™ (ProQuest, 2023) reference management software. Following the removal of duplicates, titles and abstracts were screened to identify articles suitable for inclusion. A full-text review of all selected articles was undertaken by one reviewer to determine articles for final inclusion. Instances of unclear eligibility were discussed with the second reviewer. When consensus on inclusion could not be established, a third reviewer was available to provide a final decision. The reasons for exclusion were recorded and are displayed within the PRISMA flowchart (Figure 1). Additionally, Web of Science™ (Clarivate) was used to undertaken bidirectional reference screening of eligible studies to ensure additional relevant literature was identified (Horsley, Dingwall, and Sampson, 2011). Academic work and publications by the authors of included studies were also screened to identify relevant grey literature.

 The following data items from included studies were manually extracted by one author and recorded; sample size, ECG characteristics assessed, aetiologies assessed and results.

 A risk of bias (RoB) assessment was performed using the JBI critical appraisal tools relevant to each study's methodology (Appendices C and D). Overall RoB was determined by the reviewers' overall opinion following assessment against the criteria contained within the tool.

 A narrative synthesis was chosen to present the findings of this review. Meta-analysis was not performed due to the absence of intervention effect estimates and variation in assessed aetiologies and outcomes in the included studies.

**RESULTS**

Application of the electronic database search strategy yielded a total of 4,072 records. MEDLINE produced 326 results, and CINAHL Plus and EMBASE produced 3,167 and 638 results respectively. After duplicate screening using RefWorks™ (ProQuest, 2023), a total of 3931 records were available for title and abstract review. 3925 records were removed via title and abstract screening. After obtaining the full texts of six articles, three were selected for final inclusion (Bergum *et al.*, 2016; Nguyen *et al.*, 2020; Kim *et al.*, 2021). Manual reference screening identified no further articles meeting the inclusion criteria. Grey literature searching found one eligible study within a PhD thesis (Skjeflo *et al.*, 2019).

 A PRISMA flowchart (Page *et al.*, 2021b) was produced to illustrate the study selection process (see Figure 1).

**FIGURE 1: PRISMA FLOWCHART**

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**STUDY CHARACTERISTICS**

A total of four reports from three studies were selected for final inclusion. These comprised of two published case series and one retrospective cohort study. One case series was unpublished and contained within a PhD thesis (Skjeflo *et al.*, 2019). A report of a group of patients with a specific condition without a comparator group was interpreted as a case series, as per the definition provided by Dekkers *et al.* (2012). The study by Nguyen *et al*. (2020) compared patients with bradycardic and non-bradycardic PEA and therefore was interpreted as a cohort study.

**RISK OF BIAS IN STUDIES**

 The overall RoB of all included case series (n = 3) was moderate. No case series were able to demonstrate consecutive inclusion of patients, and two studies were unable to include over 50% of eligible patients due to unavailable clinical data, which gives risk to selection and reporting bias. One cohort study was included and found to be at low risk of bias. The full results of RoB assessments are contained within appendices C and D.

Table 3: Results of individual studies

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| --- | --- | --- | --- | --- | --- | --- | --- |
| **Reference/****Study type/** **No. of patients/****Setting** | **ECG components assessed** | **Method of aetiology assessment** | **Aetiologies assessed** | **Findings** | **Study strengths** | **Study weaknesses** | **Notes** |
| **Bergum *et al.* (2016)**Case series51In-hospital | P waveHeart rateQRS durationQT intervalQTc | Determined by an ‘aetiology study group’ containing anaesthesiologists, cardiologists and a pathologist after a review of patient clinical details, cardiac arrest episode and post-cardiac arrest course. | Cardiac4Hs and 4TsOther (aortic rupture, sepsis, cancer)Mechanical (cardiac tamponade, pulmonary embolus, tension pneumothorax, hypovolemia) and non-mechanical causes | No unique cause-specific pattern of ECG was identified90% (46/51) patients had QRS >120ms | ProspectiveCauses assessed using diagnostics | Single centreSmall sample size | Patients from same database as Skjeflo *et al.* (2019) |
| **Skjeflo *et al.* (2019)**Case series63 In-hospital | Heart rateQRS duration(In the last 18 minutes of resuscitation prior to ROSC or death) | Determined by an ‘aetiology study group’ containing anaesthesiologists, cardiologists and a pathologist after a review of patient clinical details, cardiac arrest episode and post-cardiac arrest course. | ‘Cardiac’ vs non-cardiac | QRS width narrowed before ROSC and widened before death in patients with a cardiac aetiology.QRS width remained unchanged before ROSC or death in non-cardiac aetiologies.HR increased before ROSC in cardiac and non-cardiac aetiologies.HR remained unchanged in cardiac and non-cardiac aetiologies before death. | ProspectiveDid not use ‘4 Hs and 4 Ts’ to categorise aetiologies | Small sample sizeHeterogenous group of ‘other’ aetiologiesDuration of resuscitation not providedNo numerical data provided | PhD thesisPatients from same database as Bergum *et al.* (2016) |
| **Nguyen *et al.* (2020)**Retrospective cohort study176In-hospital | Heart rate | Review of clinical information, patient notes, resuscitation episode, death note and discharge summary by two independent investigators. | All | No relationship was seen between aetiology and the development of bradycardic or non-bradycardic PEA | Used multiple hospital settingsComprehensive review of causes of arrest | Used clinician interpretation of the cause rather than diagnostic findings |  |
| **Kim *et al.* (2021)**Retrospective case series617In-hospital | QRS duration | Laboratory test results (hyperkalaemia defined as a serum potassium level >5.5mmol/L) | Hyperkalaemia | Narrow QRS mean potassium: 4.6mmol/LWide QRS mean potassium: 5.4mmol/L49.6% (n = 55/111) in the wide QRS group had hyperkalaemia26.7% (n = 135/506) in the narrow QRS group had hyperkalaemia | Adjusted for confoundersLarge sample size | Single centreRetrospectiveNo patient outcomes reported |  |
| ROSC = return of spontaneous circulation, HR = heart rate, PEA = pulseless electrical activity |

**RESULTS OF SYNTHESES**

**Heart rate**

 Three studies investigated the relationship between the heart rate [HR] and aetiology of PEA. Bergum *et al.* (2016) undertook a single-centre, prospective study and aimed to evaluate the relationship between the cause of cardiac arrest and the presenting ECG characteristics in adult patients with PEA. The presumed aetiology of cardiac arrest was established via the evaluation of pre-arrest clinical information, the cardiac arrest episode and post-arrest course by a group of anaesthesiologists, cardiologists and a pathologist. Out of 144 patients who received cardiopulmonary resuscitation due to PEA, defibrillator data and a cause of arrest was available in 51 patents. Patients were divided into six groups determined by their HR and QRS width (narrow-slow, normal, narrow-fast, wide-slow, wide, wide-fast). Aetiologies were grouped into ‘cardiac’ causes or those included with the traditional ‘4 Hs and 4 Ts’; hypoxia, hypovolemia, hypo-/hyperkalemia/metabolic, hypo-/hyperthermia, thrombosis – coronary or pulmonary, tension pneumothorax, tamponade – cardiac, toxins (Soar *et al.*, 2021). When presented graphically, a wide distribution of causes across all ECG characteristic groups was seen, with no ECG patterns uniquely associated with either group of aetiologies. A further graphical evaluation of ‘mechanical’ and ‘non-mechanical’ causes also revealed no clear correlation with any ECG group. No differences were seen between aetiologies and the rate of QRS complexes during PEA. A median HR of 57bpm (interquartile range [IQR] 41-66bpm) was seen patients with a ‘cardiac’ aetiology (myocardial infarction, cardiac tamponade and heart failure). In patients with an aetiology listed within the traditional 4 H’s and 4 T’s the median HR was 48bpm (IQR 35-65bpm). When individual aetiologies were assessed, patients with PEA due to hypovolemia had a median HR of 55bpm (IQR 44-68bpm), 46bpm (35–60bpm) in hypoxia, and 59bpm (52–78bpm) in cases of myocardial infarction, however no further analysis was performed to determine the statistical significance of these differences.

 Conversely, Nguyen *et al.* (2020) examined the relationship between respiratory arrest and the development of bradycardic PEA, defined as a HR less than 60bpm. This study included 176 patients, with 66 (37.5%) experiencing bradycardic PEA and 110 (62.5%) having non-bradycardic PEA. This distribution of patients is contrary opposing to the findings of Bergum *et al.* (2016), who found the majority of patients included within their study had a bradycardic HR heart rate at the onset of PEA. The cardiac arrest aetiology was determined by two independent investigators who reviewed patient notes, discharge summaries and clinical data. 36.4% of patients with bradycardic PEA had a prior respiratory arrest, compared to 27.3% of those with non-bradycardic PEA (p = 0.24). This led to the conclusion that there was no association between preceding respiratory arrest and bradycardic PEA arrest. When assessing for other causes, the authors found that patients with bradycardic PEA were more likely to have an arrest caused by myocardial infarction, cardiac tamponade, electrolyte abnormalities and pulmonary embolism. Acidaemia, shock and unknown aetiologies were more prevalent in patients with non-bradycardic PEA. Due to small sample sizes, no analysis of the statistical significance of these findings was undertaken.

Finally, Skjeflo *et al.* (2019) utilized the same database as Bergum *et al.* (2016) and included 63 patients with a diagnosed cause of cardiac arrest. This study investigated the dynamic changes of ECG characteristics during resuscitation and their relationship with the aetiology of cardiac arrest. The study categorised causes as cardiac or non-cardiac and divided them based on outcomes (return of spontaneous circulation [ROSC] or no-ROSC). ECG measurements were then taken from the last 18 minutes of resuscitation before ROSC or death (no-ROSC). Patients with both cardiac and non-cardiac aetiologies displayed an increase in HR prior to ROSC and no change in those without ROSC. These findings were displayed via graphs and no additional statistical analysis was provided for reference, thus limiting analysis of the differences between each group.

**QRS width**

Three studies evaluated the QRS width in PEA and its relationship with the aetiology of cardiac arrest. Bergum *et al.* (2016) reported no relationship was seen between QRS duration and the aetiology within their study. 90% (46/51) of cases with available defibrillator data had a ‘wide’ QRS (>120ms), and only 6% (3/51) had a ‘normal’ ECG pattern (QRS duration <120ms and HR 60-100bpm). Additionally, evaluations of the ECG characteristics of several individual aetiologies revealed patients with myocardial infarction, cardiac tamponade, heart failure, hypoxia, hypovolemia, and pulmonary embolus all had a clinically ‘wide’ median QRS widths ranging between 165-240ms.

 Skjeflo *et al.* (2019) reported noticeable differences in changes to the QRS width during resuscitation between patients with cardiac and non-cardiac aetiologies. Patients with cardiac aetiology had wider QRS width, which narrowed prior to ROSC being obtained, while patients with no-ROSC displayed a continually increasing QRS width during resuscitation. Patients with non-cardiac aetiologies showed little change in QRS width before ROSC or no-ROSC. As previously discussed, no numerical data was provided within the results of this study and findings were displayed within graphs.

 Kim *et al.* (2021) focused on the relationship between QRS width and the presence of hyperkalaemia in patients with PEA. Among the 617 PEA episodes with ECG records and serum potassium measurements available, 111 had a wide QRS (>120ms) and 506 had a narrow QRS (<120ms). The authors found those with a narrow QRS had a mean serum potassium of 4.6mmol/L compared to 5.4mmol/L in those with a wide QRS (IQR 4.4-6.7 versus 4.0-5.6, p <0.0001). Patients with wide QRS had a greater incidence of hyperkalaemia (serum potassium >5.5mmol/L) compared to those without (26.7% versus 49.6%, *p* = 0.001). In the 149 patients presenting with OHCA, 108 (72.5%) presented with a narrow QRS, and 41 (27.2%) with a wide QRS. Patients with wide QRS were more likely to be older (68.0 vs 64.0, *p* = 0.047), male (67.6% vs 57.3%, *p* = 0.047) and have a history of diabetes (43.5% vs 31.6%, *p* = 0.017). After adjusting for confounding variables, wide QRS PEA was associated with hyperkalaemia with an odds ratio (OR) of 2.86 (95% CI 1.80–4.53, *p* <0.001). These findings were repeated in patients with chronic kidney disease (OR = 4.56, 95% CI 1.31–15.82, *p* = 0.017) and without (OR = 2.79, 95% CI 1.63–4.77, *p* < 0.001).

**Other ECG components**

 Only one study investigated additional ECG components. Bergum *et al.* (2016) found no differences in the incidence of P waves between aetiologies. Patients with myocardial infarction (n=13) and heart failure (n=5) had the longest median QT (518ms and 595ms) and QTc intervals (504ms and 504ms). Patients with hypoxia and thrombus/pulmonary embolism had the shortest median QT intervals (479ms and 494ms). The QTc intervals were shortest in patients with cardiac tamponade (446ms) and thrombus/pulmonary embolism (426ms). No statistical analysis to determine the significance of the difference between the ECG characteristics of each group was undertaken.

**DISCUSSION**

 Previously proposed theoretical models of PEA have suggested ECG characteristics will reflect the pathophysiological responses to certain aetiologies seen in patients prior to cardiac arrest. For example, Mehta and Brady (2012), Littman, Bustin and Haley (2014) and Jentzer *et al.* (2016), suggested patients with a ‘mechanical’ aetiology, such as tension pneumothorax, cardiac tamponade or pulmonary embolus, would have narrow complex, tachycardic rhythms on initial presentation. Conversely, wide complex PEA has been proposed to occur due to metabolic abnormalities (Mehta and Brady, 2012; Littman, Bustin and Haley, 2014). These concepts are not fully supported by the literature identified within this review, and therefore should not be used as a basis for determining resuscitation strategy in isolation. Within Bergum *et al.*’s study, just two out of 18 patients with a ‘mechanical’ aetiology were tachycardic, both had a wide QRS, and ten were bradycardic. Furthermore, 90% (n = 46/51) of patients had a wide complex QRS irrespective of cause. Skjeflo *et al.* (2019) also found both ‘cardiac’ and ‘non-cardiac’ causes, defined as all other aetiologies except myocardial infarction or cardiac tamponade caused by myocardial infarction, produced clinically wide QRS complexes. A similar pattern of change in patients with in-hospital cardiac arrest was also observed with the work of Attin *et al.* (2015), who described QRS prolongation in the last hour before cardiac arrest in all subjects within their study. This may therefore provide further evidence the reasons for QRS prolongation in PEA are multi-faceted and cannot be attributed to isolated pathologies.

 A retrospective study by Shan *et al.* (2022), found that patients with a respiratory aetiology frequently displayed an abrupt decrease in HR prior to cardiac arrest and suggested this may be a cause of PEA. In these circumstances, the development of PEA may be explained by falling cardiac output secondary to bradycardia caused by myocardial ischemia due to systemic hypoxia. However, Nguyen *et al*. (2020) reported a statistically non-significant difference between the incidence of bradycardic PEA (<60bpm) and non-bradycardic PEA in patients with prior respiratory dysfunction, and found bradycardic PEA was not specific to respiratory causes alone. Attin *et al.* (2015) reported the development of bradycardic PEA in 82% (n = 32/39) of patients with a history of cardiac disease, and postulated this occurs due to an imbalance between the parasympathetic and sympathetic nervous system. Unfortunately, no aetiology assessment was performed in these subjects to provide evidence to support this theory. Further to this, Holmstrom *et al.* (2022) found bradyarrhythmia to be the second most dominant cause of PEA cardiac arrest, with 80% of these caused by a conduction block.

As argued by Tripepi *et al.* (2010), the risk of selection bias is of paramount importance in aetiological research as may limit the external validity of results. Three for the four studies within this review were determined to be at a moderate risk of bias due to a lack of consecutive inclusion of participants. Bergum *et al.* (2016), Skjeflo *et al.* (2019) and Kim *et al.* (2021) all reported difficulty in matching ECG records with patient data, or ECG records of insufficient quality to allow for analysis. Improvements to defibrillator analysis software and the routine inclusion of defibrillation files into resuscitation registries has been suggested as a solution to this issue (Nordseth *et al.,* 2024).

 The utility of ECG characteristics in identifying patients with metabolic disturbances was only investigated in one study. Kim *et al.* (2021) reported a statistically significant association between wide QRS complexes and hyperkalaemia. Whilst this may appear to support the theory that patients with wide QRS complexes may have underlying metabolic abnormalities, there are several factors inherent to the retrospective nature of this study provide important limitations to the clinical application of these findings. As proposed by Martin *et al.* (1989), serum potassium may increase during cardiac arrest due to poor tissue perfusion and contribute to the widening of QRS complexes in PEA, rather than being the primary cause. Furthermore, Vallentin *et al.* (2022) suggested calcium chloride may be harmful when administration is guided by ECG changes indicative of hyperkalaemia. Within their analysis, ROSC was achieved in 20% (n=9) of patients receiving calcium chloride, and in 39% (n=23) of those treated with a placebo. Just 2.2% (n=1) survived to 30 days in the calcium group compared to 13.6% (n=8) receiving a placebo. This study indicates that calcium chloride should not be initiated based on ECG characteristics in isolation. This is furthermore confirmed by the findings of this review, where wide complex PEA was not demonstrated to occur due to metabolic disturbances alone.

 The assessment of dynamic changes to ECG components throughout resuscitation may have the potential to yield diagnostic information and aid assessment of the response to resuscitation. Skjeflo *et al.* (2019) demonstrated that the QRS width of patients with cardiac aetiologies was wider than those with non-cardiac aetiologies when recorded 18 minutes before ROSC or death. Interestingly, the QRS width then narrowed prior to ROSC in patients with cardiac aetiologies, while it remained unchanged in those with non-cardiac aetiologies. The underlying reasons for these ECG changes remain unclear. Outside the context of cardiac arrest, prolonged QRS duration has been linked to cardiovascular disease or structural cardiac issues (Chen *et al.*, 2021). Experimental studies have also shown that myocardial ischemia can directly affect cardiac depolarisation and conduction velocity (Almer *et al.*, 2016; Good *et al.*, 2021). This may explain the differences observed between cardiac and non-cardiac aetiologies, where in the latter, cardiac electrophysiology is preserved due to the absence of direct insult to the myocardium. Based on these findings, in patients with suspected cardiac aetiologies, narrowing of the QRS width during resuscitation may indicate improving myocardial perfusion. Conversely, widening QRS complexes may suggest an inadequate response to treatment and the need to consider alternative strategies.

**LIMITATIONS**

This review has several limitations. Only English-language literature was included, potentially excluding relevant studies published in other languages. Additionally, subject matter experts were not consulted during the review process, which could have identified additional relevant literature. Studies published before 1st January 2013 were excluded to obtain results that reflect contemporary resuscitation practice and diagnostics. When making this decision, the references of articles proposing the use of ECG characteristics as indicators of aetiology in PEA were assessed and no relevant clinical studies were identified. Nonetheless, this date limit may still have excluded additional studies supporting the use of ECG characteristics for this purpose.

One limitation of research assessing the aetiologies of PEA lies in their respective methods of determining the correct aetiology and how they are categorised. Bergum *et al.* (2016) and Skjeflo *et al.* (2019) grouped causes based on broad descriptions of the mechanism, such as ‘cardiac’ or ‘non-cardiac’, or ‘mechanical’ and ‘non-mechanical’, rather than specific causes. This approach limits the usefulness of ECG characteristics as indicators of specific pathologies that may require different interventions. For example, cardiac tamponade and myocardial infarction were both included within the ‘cardiac’ group of aetiologies, despite requiring distinctly different treatments. Whilst these studies only included cases with presumed reliable diagnoses, the methods used to determine the aetiology in cases that resulted in death may lack accuracy and objectivity, as they were based on clinical opinion rather than autopsy findings. Moreover, Holmstrom *et al.* (2022) reported that 65% of PEA cases had an undetermined trigger in a retrospective analysis of medical records of 97 survivors. Therefore, the true diagnostic accuracy of both studies may not be fully known.

Additionally, there is inconsistency amongst the included studies on the timing of assessment of ECG components. Therefore, the ECG measurements obtained may have been influenced by treatments or physiological deterioration during resuscitation and not represent the initial ECG components at the onset of cardiac arrest.

**CONCLUSION**

The current available evidence does not provide clear support for using ECG characteristics in isolation as reliable indicators of the underlying causes of PEA cardiac arrest. The reported values for certain subtypes of aetiology do not match the theoretical models proposed within the literature. Additionally, the methods used to determine aetiologies may lack accuracy and consistency, relying on clinical opinion rather than pathological findings at autopsy.

Future research should utilise data from prehospital services and witnessed cardiac arrests in order to provide a more accurate understanding of the ECG characteristics in the early stages of PEA OHCA. This should include combined defibrillator or ECG data and patient clinical data. Studies focusing on monitored patients who deteriorate into PEA following a confirmed diagnosis, rather than undifferentiated cases, may enhance our understanding of the ECG characteristics associated with specific pathologies and how these manifest in early cardiac arrest. Finally, when available, autopsy data should be incorporated to improve the evaluation of aetiologies in patients who do not survive resuscitation.

**Registration and Protocol**

This systematic review was originally undertaken and submitted as part of a Masters in Prehospital Critical Care therefore was not registered prior to commencement. A protocol was created as part of this work and is available upon request. No alterations were made to the design of the review.

**Ethics**

Ethics approval was not necessary as no primary research was undertaken and all included studies received their own respective ethics approval.

**Conflict of Interest**

None declared.

**Funding**

No funding was sought to facilitate the undertaking of this review.

**Contributions**

 This systematic review was originally undertaken and submitted as part of a Masters in Prehospital Critical Care.

 BG developed the aim and objectives, undertook the literature searches, data extraction, RoB assessments and drafted the manuscript. SL provided continuous supervision and secondary review throughout all areas. Both BG and SL contributed to the final version of the manuscript.

I would also like to acknowledge the valuable feedback and academic support provided by Mary Halter throughout this project.

**APPENDIX A: EMBASE search strategy**

1 ("narrow QRS" or "narrow complex" or "wide QRS" or "wide complex").ab,kf,ot,ti.

2 (tachy\* or brady\* or rate or complex\* or wide or narrow or QRS or "p wave" or "t wave" or activity or ECG or EKG or electrocard\*).ab,ot,ti.

3 (PEA or EMD or "electromechanical dissociation" or "pulseless electrical activity").ab,ot,ti.

4 (aetiolog\* or etiolog\*).ab,ot,ti.

5 2 and 3 and 4

6 limit 5 to (human and english language and yr="2013 -Current" and (adult <18 to 64 years> or aged <65+ years>))

7 1 and 4

8 limit 7 to (human and english language and yr="2013 -Current" and (adult <18 to 64 years> or aged <65+ years>))

9 3 and 4

10 limit 9 to (human and english language and yr="2013 -Current" and (adult <18 to 64 years> or aged <65+ years>))

11 ("ECG characteristics" or components).ab,ot,ti. 734571

12 3 and 11

13 limit 12 to (human and english language and yr="2013 -Current" and (adult <18 to 64 years> or aged <65+ years>))

14 3 and 4 and 11

15 limit 14 to (human and english language and yr="2013 -Current" and (adult <18 to 64 years> or aged <65+ years>))

16 (metabolic or mechanical).ab,ot,ti.

17 (ECG or EKG or electrocard\* or QRS).ab,ot,ti.

18 3 and 16 and 17

19 limit 18 to (human and english language and yr="2013 -Current" and (adult <18 to 64 years> or aged <65+ years>))

20 (hyper\* or hypo\*).ab,ot,ti.

21 3 and 17 and 20

22 limit 21 to (human and english language and yr="2013 -Current" and (adult <18 to 64 years> or aged <65+ years>))

**APPENDIX B: CINAHL Plus and MEDLINE search strategy**

S1 TX tachy\* OR brady\* OR rate OR complex\* OR wide OR narrow OR QRS OR ‘p wave’ OR ’t wave’ OR activity OR ECG OR EKG OR electrocard\*

S2 TX PEA OR EMD OR ‘electromechanical dissociation’ OR ‘pulseless electrical activity’

S3 TX aetiolog\* OR etiolog\* OR cause\* OR diagnos\* OR condition\* OR associat\*

S4 S1 AND S2 AND S3

S5 TI, AB, MW 'narrow QRS' OR 'narrow complex' OR 'wide QRS' OR 'wide complex'

S6 TI, AB, MW tachy\* OR brady\* OR rate OR complex\* OR wide OR narrow OR QRS OR 'p wave' OR 't wave' OR activity OR ECG OR EKG OR electrocard\*

S7 TI, AB, MW PEA OR EMD OR 'electromechanical dissociation' OR 'pulseless electrical activity'

S8 TI, AB, MW aetiolog\* OR etiolog\*

S9 S6 AND S7 AND S8

S10 S5 AND S8

S11 S7 AND S8

S12 TI, AB, MW 'ECG characteristics' OR components

S13 S7 AND S12

S14 S7 AND S8 AND S12

S15 TI, AB, MW metabolic OR mechanical

S16 TI, AB, MW ECG OR EKG OR electrocard\* OR QRS

S17 S7 AND S15 AND S16

S18 TI, AB, MW hyper\* OR hypo\*

S19 S7 AND S16 AND S18

**APPENDIX C: Risk of bias assessment results – case series**

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Reference** | **Q1** | **Q2** | **Q3** | **Q4** | **Q5** | **Q6** | **Q7** | **Q8** | **Q9** | **Q10** | **Overall RoB** |
| Bergum *et al.* (2016) |  |  |  |  |  |  |  |  |  |  | Moderate |
| Skjeflo *et al.* (2019) |  |  |  |  |  |  |  |  |  |  | Moderate |
| Kim *et al.* (2021) |  |  |  |  |  |  |  |  |  |  | Moderate |
| *Q1: Were there clear criteria for inclusion in the case series? Q2: Was the condition measured in a standard, reliable way for all participants included in the case series? Q3: Were valid methods used for identification of the condition for all participants included in the case series? Q4: Did the case series have consecutive inclusion of participants? Q5: Did the case series have complete inclusion of participants? Q6: Was there clear reporting of the demographics of the participants in the study? Q7: Was there clear reporting of clinical information of the participants? Q8: Were the outcomes or follow up results of cases clearly reported? Q9: Was there clear reporting of the presenting site(s)/clinic(s) demographic information? Q10: Was statistical analysis appropriate?* (Munn *et al.*, 2020) |

|  |  |  |  |
| --- | --- | --- | --- |
| **Key:** | Yes | No | Unclear |

APPENDIX D: Risk of bias assessment results - cohort studies

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Reference** | **Q1** | **Q2** | **Q3** | **Q4** | **Q5** | **Q6** | **Q7** | **Q8** | **Q9** | **Q10** | **Q11** | **Overall RoB** |
| Nguyen *et al.* (2020) |  |  |  |  |  |  |  |  |  |  |  | Low |
| *Q1: Were the two groups similar and recruited from the same population? Q2: Were the exposures measured similarly to assign people to both exposed and unexposed groups? Q3: Was the exposure measured in a valid and reliable way? Q4: Were confounding factors identified? Q5: Were strategies to deal with confounding factors stated? Q6: Were the groups/participants free of the outcome at the start of the study (or at the moment of exposure)? Q7: Were the outcomes measured in a valid and reliable way? Q8: Was the follow up time reported and sufficient to be long enough for outcomes to occur? Q9: Was follow up complete, and if not, were the reasons to loss to follow up described and explored? Q10: Were strategies to address incomplete follow up utilized? Q11: Was appropriate statistical analysis used?* (Moola *et al.*, 2020) |

|  |  |  |  |
| --- | --- | --- | --- |
| **Key:** | Yes | No | Unclear |

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