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Neurological outcomes after traumatic cardiopulmonary arrest: a systematic review

Daniel Shi,[1] Christie McLaren,[1] Chris Evans[2]

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[1]School of Medicine, Queen's University, Kingston, Ontario, Canada
[2]Emergency Medicine, Queen's University, Kingston, Ontario, Canada

Correspondence to
Daniel Shi; dshi@qmed.ca

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ABSTRACT

Background Despite appropriate care, most patients do not survive traumatic cardiac arrest, and many survivors suffer from permanent neurological disability. The prevalence of non-dismal neurological outcomes remains unclear.

Objectives The aim of the current review is to summarize and assess the quality of reporting of the neurological outcomes in traumatic cardiac arrest survivors.

Data sources A systematic review of Embase, Medline, PubMed, Cumulative Index to Nursing and Allied Health Literature (CINAHL), and ProQuest databases was performed from inception of the database to July 2020.

Study eligibility criteria Observational cohort studies that reported neurological outcomes of patients surviving traumatic cardiac arrest were included.

Participants and interventions Patients who were resuscitated following traumatic cardiac arrest.

Study appraisal and synthesis methods The quality of the included studies was assessed using ROBINS-I (Risk of Bias in Non-Randomized Studies - of Interventions) for observational studies.

Results From 4295 retrieved studies, 40 were included (n=23 644 patients). The survival rate was 9.2% (n=2168 patients). Neurological status was primarily assessed at discharge. Overall, 45.8% of the survivors had good or moderate neurological recovery, 29.0% had severe neurological disability or suffered a vegetative state, and 25.2% had missing neurological outcomes. Seventeen studies qualitatively described neurological outcomes based on patient disposition and 23 studies used standardized outcome scales. 28 studies had a serious risk of bias and 12 had moderate risk of bias.

Limitations The existing literature is characterized by inadequate outcome reporting and a high risk of bias, which limit our ability to prognosticate in this patient population.

Conclusions or implications of key findings Good and moderate neurological recoveries are frequently reported in patients who survive traumatic cardiac arrest. Prospective studies focused on quality of survivorship in traumatic arrest are urgently needed.

Level of evidence Systematic review, level IV.

PROSPERO registration number CRD42020198482.

BACKGROUND

Traumatic cardiac arrest (TCA) occurs due to severe injury, most commonly from traumatic brain injury and hemorrhage.[1] Despite appropriate care, TCA has been associated with extremely low survival rates, with 2% of patients surviving to hospital discharge.[2] Some authors have even concluded that resuscitation of patients with TCA is futile and costly.[3] However, recent data from prospectively registered trauma systems in England, Spain, and North America have suggested that outcomes from TCA may be better than previously expected, with overall survival rates between 5.7% and 7.5%.[4–6] Advances in damage control resuscitation and our understanding of its pathophysiology have led to improvements in the contemporary management of TCA, which is at least partially responsible for the observed increase in overall survival.[7]

The prognostication of patients with TCA is an important consideration for patients, families, and health providers that initiate resuscitative efforts, as after survival the main treatment goal is a favorable neurological outcome.[3 8] Poor outcomes after cardiac arrest of any etiology have been attributed to hypoxic-ischemic brain injury.[9] The extent of this brain injury is an important predictor of unfavorable neurological outcomes, which are defined by death from neurological cause, persistent vegetative state, or severe neurological disability.[9] Most studies examining cardiac arrest outcomes use the Cerebral Performance Categories (CPCs) or the Glasgow Outcome Scale (GOS) to report neurological status.[9] Other scales that have demonstrated value in assessing the neurological outcome of survivors include the modified Rankin Scale (mRS), the Extended Glasgow Coma Scale (GOSE), and the Functional Independence Measure (FIM).[10–12] Despite the existence of several validated measures, in many neuroprognostication studies, neurological outcomes are generally dichotomized as "good" or "poor", with no consensus on how a poor outcome is defined.[9] The neurological outcome of these patients remains unclear in the current literature. Among TCA survivors, residual neurological deficits have generally been found to be severe and disabling in small observational studies.[13 14] However, a systematic review in 2012 found that more than half of TCA survivors either make a full neurological recovery or have moderate deficits.[15]

Although previous literature has focused on summarizing the proportion of survivors and identifying resuscitation techniques to reduce mortality in traumatic arrest, minimal evidence exists that assesses the quality of neurological outcome data. Hence, we performed a systematic review to summarize the neurological outcomes of patients who survive TCA. Particular attention was placed on the variation of reporting and definitions of these outcomes between studies.

METHODS

This review was conducted in accordance with the *Cochrane Handbook for Systematic Reviews of Interventions* and followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement.[16] The protocol for this study was registered with the International Prospective Register of Systematic Reviews.

Inclusion criteria

Eligible studies included observational cohort studies that enrolled patients who experienced cardiopulmonary arrest following trauma and reported neurological outcomes. Studies examining pediatric patients were included. We excluded case reports, case series studies, reviews, and animal studies. Studies published in the English language were included. There were no restrictions on the length of follow-up, geographical location, or publication date.

Study selection and data abstraction

A systematic search of Embase, Medline, PubMed, Cumulative Index to Nursing and Allied Health Literature (CINAHL), and ProQuest was conducted from the inception of the database to July 2020. A librarian with methodological and content expertise was consulted to create the search strategies (online supplemental table 1). Medical subject headings and Emtree headings were used in their respective databases.

Two reviewers (DS and CM) independently screened the title and abstract of all included studies. Duplicate studies were removed using Covidence.[17] Studies that met the inclusion criteria were reviewed in full text by the same two reviewers independently (figure 1). Disagreements were resolved by consensus or by the decision of a third independent reviewer (CE). Interobserver agreements for the title/abstract and full text stages were calculated using Cohen's κ statistics.[18]

Data were abstracted by two independent reviewers using a piloted data abstraction form (Microsoft Excel). The primary outcome was the neurological status of TCA survivors which was abstracted from each study. Additionally, the methods used to assess neurological outcome, the mechanism of trauma, and the time point when neurological status was measured were abstracted.

Data analysis

Patients from the included studies were placed into one of four categories to describe their neurological outcome: good, moderate, poor, or vegetative. A "good" neurological outcome was defined as a full neurological recovery or having minor deficits. A "moderate" outcome was defined as having neurological disability that partially affects daily activities but having full independence. A "poor" outcome was defined as requiring any level of dependency or personal assistance in daily living. A "vegetative" outcome was defined by unresponsiveness to external stimuli and a decreased level of awareness.

The proportion of patients with "favorable" neurological outcomes (ie, patients with good or moderate outcome) versus

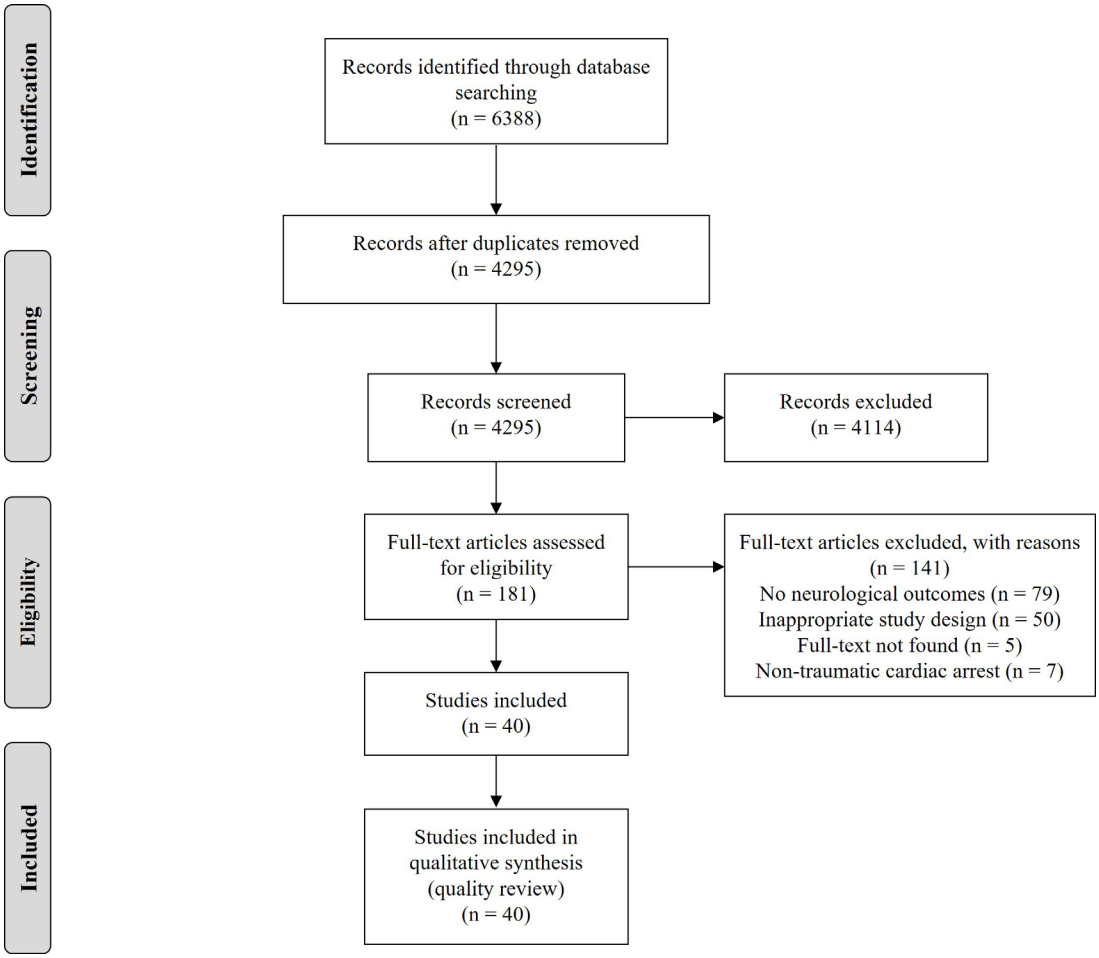

Figure 1 PRISMA diagram. PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

patients with "unfavorable" neurological outcomes (ie, patients with poor or vegetative outcome) was also calculated.

Quality assessment

The quality of included studies was assessed using ROBINS-I (Risk of Bias in Non-Randomized Studies - of Interventions) tool for observational studies. The overall risk of bias was rated as critical, serious, moderate, or low. Quality assessment was completed by two independent reviewers (DS and CM), with all conflicts resolved by consensus or discussion with a third reviewer (CE).

RESULTS

Study characteristics

After the removal of duplicates, the literature search generated 4295 citations for title and abstract review. One hundred and eighty-one qualified for full-text screening, of which 40 were included in our analysis (figure 1). The title and abstract screening showed almost perfect agreement (κ=0.83), and similar agreement was found for the full-text screening (κ=0.87). Of the included studies, 35 were retrospective cohort studies and 5 were prospective cohort studies (table 1). The included studies were published between 1983 and 2019, with 12 studies published in the past 5 years.

Table 1 Characteristics of included studies

Study identification	Design	Age group	Sample size	Survivors (n)	Mortality (%)	Blunt trauma	Penetrating trauma	Other/unknown trauma type
Alanezi[45] 2004	Prospective cohort	Mixed	50	2	96.0	4	46	0
Barnard[4] 2017	Retrospective cohort	Mixed	705	53	92.5	601	104	0
Beck[46] 2016	Retrospective cohort	Mixed	1354	9	99.3	869	226	259
Calkins[34] 2002	Retrospective cohort	Pediatric	25	2	92.0	25	0	0
Capizzani[35] 2010	Retrospective cohort	Pediatric	30	6	80.0	21	0	9
Chia[47] 2017	Retrospective cohort	Mixed	1554	38	97.6	NR	NR	1554
Chiang *etal*[48] 2015	Retrospective cohort	Adult	514	20	96.1	388	0	126
Chien[49] 2016	Retrospective cohort	Adult	396	9	97.7	197	11	188
David[50] 2007	Retrospective cohort	Adult	268	6	97.8	NR	NR	268
Deasy[51] 2012	Retrospective cohort	Mixed	2187	28	98.7	NR	NR	2187
Di Bartolomeo[19] 2005	Retrospective cohort	Adult	181	2	89.0	181	0	0
Djarv[52] 2018	Retrospective cohort	Mixed	1774	65	96.3	NR	NR	1774
Duchateau[53] 2017	Retrospective cohort	Adult	88	10	88.6	77	11	0
Evans[5] 2016	Retrospective cohort	Mixed	2300	145	92.7	1547	736	270
Falcone[54] 1995	Retrospective cohort	Adult	320	6	98.1	285	36	0
Fisher [55] 1999	Retrospective cohort	Pediatric	65	1	98.5	65	0	0
Graesner[56] 2011	Retrospective cohort	Mixed	814	221	72.9	597	52	165
Hillman[57] 2016	Retrospective cohort	Pediatric	27	4	85.2	4	7	16
Huber-Wagner[58] 2007	Retrospective cohort	Mixed	757	130	82.8	714	43	0
Keller[37] 2013	Retrospective cohort	Mixed	448	37	91.7	NR	NR	NR
Kleber[23] 2014	Prospective cohort	Mixed	71	15	79.9	40	12	19
Lawhon[20] 1995	Retrospective cohort	Mixed	47	2	95.7	NR	NR	47
Lin[59] 2016	Retrospective cohort	Pediatric	388	38	91.2	365	23	0
Love[60] 2016	Retrospective cohort	Mixed	237	7	97.0	165	72	0
Lundy[61] 2011	Retrospective cohort	Mixed	309	125	59.5	NR	NR	309
Molina[62] 2008	Retrospective cohort	Mixed	94	8	91.5	0	94	0
Mollberg[63] 2011	Retrospective cohort	Adult	294	1	99.7	90	204	0
Moore[44] 2011	Prospective cohort	Mixed	NR	56	NR	5	51	NR
Moore[64] 2016	Prospective cohort	Adult	1708	106	93.8	820	888	0
Murphy[65] 2010	Retrospective cohort	Pediatric	169	28	83.4	151	7	11
Perron[66] 2001	Retrospective cohort	Pediatric	729	184	74.8	505	81	143
Pickens[67] 2005	Retrospective cohort	Mixed	184	14	92.4	90	94	0
Powell[68] 2004	Retrospective cohort	Mixed	959	62	93.5	11	51	897
Rabinovici[69] 2014	Retrospective cohort	Mixed	67	9	86.6	17	50	0
Shimazu[70] 1983	Retrospective cohort	Mixed	267	7	97.4	217	50	0
Stratton[71] 1998	Retrospective cohort	Mixed	879	9	99.9	382	497	0
Tarmey[43] 2011	Prospective cohort	Adult	52	4	92.3	0	17	35
Vassallo[72] 2019	Retrospective cohort	Pediatric	129	7	94.6	110	19	0
Zwingmann[73] 2015	Retrospective cohort	Pediatric	152	43	71.7	145	7	0
Zwingmann[21] 2016	Retrospective cohort	Mixed	3052	649	78.7	NR	NR	3052

NR, not reported.

Patient characteristics

There were 23 644 patients included, with 2168 (9.2%) surviving to hospital discharge. The mortality rate was 90.8%. Blunt trauma (n=8687 patients) and penetrating trauma (n=3489 patients) were the main mechanisms of traumatic arrest, whereas the remaining trauma mechanisms were not classified (n=11 468) (table 1). Nine studies examined pediatric patients only (n=1714 patients), 9 studies examined adults only (n=3821 patients), and 22 studies examined a mixed population (n=18 109 patients) without providing information of how many pediatric patients were included.

Neurological outcome reporting

Seventeen studies qualitatively described their neurological outcome based on patient disposition after discharge (eg, home, nursing care, or rehabilitation) and the level of assistance required in daily activities. Thirteen studies used the GOS and reported the number of patients in each GOS category (GOS 1–5). Eight studies used the CPC and one study used the Pediatric Cerebral Performance Categories (PCPC) to assess neurological outcome.

Seven studies dichotomized neurological outcomes into "good" or "poor" categories using the GOS, CPC, or PCPC scales. Six of the seven studies considered a "good" neurological outcome as patients with CPC 1 and 2 or GOS 4 and 5 (ie, good, mild, or moderate deficits) and a "poor" neurological outcome as those with CPC 3 and 5 or GOS 1 and 3 (ie, severe or vegetative). One study used the PCPC and defined a "good" outcome as PCPC 1 and 2 (good or mild deficits) and a "poor" outcome as PCPC 3 and 5 (moderate or severe deficits, or vegetative).

One study used the FIM to assess neurological status. This study reported an average FIM score for the survivors and the number of patients who had obtained the lowest score (required assistance in daily life). The functional status of the other patients was not reported.

Neurological status was recorded primarily at patient discharge, but some studies reported outcomes up to a 4-year follow-up period.

Overall neurological outcomes

The neurological outcomes of individual studies are reported in table 2. Based on the 32 studies (n=1507 patients) that reported the number of patients for each neurological outcome category, 538 (35.7%) had good outcomes, 392 (26.0%) had moderate outcomes, 408 (27.1%) had poor outcomes, and 169 (11.2%) were vegetative.

In six studies (n=115 patients) that reported dichotomous outcomes, 62 patients (53.9%) had "good" outcomes and 53 patients (46.1%) had "poor" outcomes. In the one study (n=38 patients) that used the PCPC, 12 (31.6%) had "good" outcomes and 26 (68.4%) had "poor" outcomes. One study (n=184 patients) that used the FIM reported an average score of 38.9 (range: 18–126), 7 patients with severe deficits and 177 patients that had either good recovery or moderate or severe deficits.

Based on all 40 studies (n=2168 patients) included in this review, 992 (45.8%) had favorable outcomes, 630 (29.0%) had unfavorable outcomes, and 546 (25.2%) were missing. The results of the studies that used the PCPC and the FIM were included in the missing category, as the neurological status of the survivors was unclear and could not be categorized.

Neurological outcomes for pediatric studies

Of the seven studies (n=87 patients) that examined only pediatric populations and reported the number of patients for each neurological outcome category, 37 (42.5%) had good outcomes, 19 (21.8%) had moderate outcomes, 18 (20.7%) had poor outcomes, and 13 (14.9%) were vegetative. Hence, 56 patients (64.4%) had favorable outcomes and 31 (35.6%) had unfavorable outcomes.

Neurological outcomes for adult studies

Of the nine studies (n=164 patients) that examined only adult populations, 119 patients (72.6%) had favorable outcomes, 41 (25.0%) had unfavorable outcomes, and 4 (2.4%) had missing outcomes. Of the six studies (n=129 patients) that reported the number of patients for each neurological outcome category, 87 (67.4%) had good outcomes, 15 (11.6%) had moderate outcomes, 6 (4.7%) had poor outcomes, 17 (13.2%) were vegetative, and 4 (3.1%) had missing outcomes.

Assessment of quality

The quality of all included studies (n=40 studies) was assessed. Twenty-eight studies were at a serious risk of bias and 12 studies were at a moderate risk of bias (table 3). In general, the studies were well reported. The confounding domain was the primary source of bias, as most studies did not consider many potential confounders, including age, resuscitation technique, and type of trauma. The outcome measurement domain was also a significant source of bias, as most studies used physician-reported neurological outcomes, which were described qualitatively in the studies. Hence, these studies were rated as a serious risk of bias in this domain. Finally, there was moderate to serious risk of bias for selective reporting, as some studies did not report outcomes for each neurological category.

DISCUSSION

The current review is the first study to focus on neurological outcomes across a large patient population (n=23 644 patients). We report a survival rate of 9.2%, which is one of the most optimistic findings to date for outcomes following TCA. In the current review, favorable neurological outcomes were frequently reported (45.8% with full recovery or moderate disability), suggesting that outcomes from TCA may be more favorable than previously expected.[3]

Previous literature suggests that prognosis after traumatic arrest is extremely poor. Many studies reported only a small number of survivors, all with severe neurological disability.[3 14 19 20] However, in 2012, new studies were conducted and a systematic review found that good and moderate neurological outcomes were reported in 57.4% of survivors.[15] A large retrospective study published in 2016 supports these findings and reported good and moderate neurological outcomes in up to 75.0% of survivors.[21] Despite these findings, neurological outcomes continue to be debated, as newer studies with larger numbers of survivors report good and moderate outcomes in only 4.3% to 27.0% of survivors.[22 23] The findings of the current review suggest that those who survive traumatic arrest may have a favorable prognosis. The observed improvement in neurological outcomes is likely connected to novel advances in damage control resuscitation and refinement of treatment of guidelines.[7]

A secondary aim of this review was to assess the quality of the reporting of neurological outcomes. In most of the included studies, neurological status was qualitatively described. As the exact deficits were often not described, it was difficult to quantify the extent of the impairments and classify the neurological outcomes of these patients. Alternatively, patient disposition (eg, home, nursing care, rehabilitation) and dependence

Table 2 Neurological outcomes of included studies

Study identification	Neurological scale	Time point	Qualitative outcomes				
			Good	Moderate	Poor	Vegetative	Missing
Alanezi[45] 2004	Qualitative	Discharge	1	0	1	0	0
Barnard[4] 2017	GOS	Discharge	24*	N/A	9†	N/A	20
Beck[46] 2016	CPC	Discharge	6*	N/A	3	0	0
Calkins[34] 2002	Qualitative	Discharge	2	0	0	0	0
Capizzani[35] 2010	Qualitative	Discharge	2	1	3	0	0
Chia[47] 2017	CPC	Discharge	15*	N/A	23†	N/A	0
Chiang[48] 2015	CPC	Discharge	12*	N/A	8†	N/A	0
Chien[49] 2016	CPC	Discharge	3*	N/A	6†	N/A	0
David[50] 2007	CPC	Discharge	2*	N/A	4†	N/A	0
Deasy[51] 2012	GOS	1 year	0	2	2	1	23
Di Bartolomeo[19] 2005	GOS	4 years	0	0	2	0	0
Djarv[52] 2018	CPC	Discharge/30 days	15	7	6	0	37
Duchateau[53] 2017	CPC	Discharge	7	2	1	0	0
Evans[5] 2016	GOS	Discharge	24	6	15	3	97
Falcone[54] 1995	Qualitative	Discharge	4	0	2	0	0
Fisher[55] 1999	Qualitative	Discharge	0	0	0	1	0
Graesner[56] 2011	GOS	Discharge	72	53	48	40	8
Hillman[57] 2016	Qualitative	Variable	1	0	1	0	2
Huber-Wagner[58] 2007	GOS	Discharge	15	13	15	6	81
Keller[37] 2013	GOS	Variable	12	2	2	1	20
Kleber[23] 2014	GOS	Discharge	1	3	10	1	0
Lawhon[20] 1995	Qualitative	Discharge/3 years	0	0	1	1	0
Lin[59] 2016	PCPC	Discharge	12	26‡	N/A	N/A	0
Love[60] 2016	Qualitative	Discharge	4	0	3	0	0
Lundy[61] 2011	Qualitative	Discharge	36	0	89	0	0
Molina[62] 2008	Qualitative	Discharge	8	0	0	0	0
Mollberg[63] 2011	Qualitative	Discharge	0	0	1	0	0
Moore[64] 2011	Qualitative	Discharge	46	9	1	0	0
Moore[44] 2016	GOS	Discharge	72	13	0	17	4
Murphy[65] 2010	Qualitative	Discharge	16	3	7	2	0
Perron[66] 2001	FIM	Discharge	177§	0	7	0	0
Pickens[67] 2005	Qualitative	Discharge	11	1	0	2	0
Powell[68] 2004	Qualitative	Discharge	15	6	5	0	36
Rabinovici[69] 2014	Qualitative	Discharge	7	1	1	0	0
Shimazu[70] 1983	Qualitative	30 days post admission	4	0	2	0	1
Stratton[71] 1998	CPC	Discharge	3	1	2	3	0
Tarmey[43] 2011	GOS	Discharge	4	0	0	0	0
Vassallo[72] 2019	GOS	Discharge/30 days	2	2	1	0	2
Zwingmann[73] 2015	GOS	After resuscitation	14	13	6	10	0
Zwingmann[21] 2016	GOS	After resuscitation	193	201	174	81	0
Total		Favorable: 992			Unfavorable: 630		Missing: 546

*Reported as good or moderate.
†Reported as poor or vegetative.
‡Reported as moderate, poor, or vegetative.
§Reported as good, moderate, or poor.
CPC, Cerebral Performance Categories; FIM, Functional Independence Measure; GOS, Glasgow Outcome Scale; N/A, not available; PCPC, Pediatric Cerebral Performance Categories.

on daily support had to be used as indicators of neurological status. Furthermore, as an outcome measurement scale was not used, there is likely some degree of variation and biases among physician-reported outcomes. Several included studies reported dichotomous outcomes using a standardized scale by combining CPC 1 to 2 (good and moderate) as a "good" outcome and CPC 3 to 5 (severe, vegetative, death) as a "poor" outcome. However, the definition of a "good" and "poor" outcome varied between studies as CPC 3 was historically considered a "good" outcome.[24] This reflects the differing values and preferences in the evaluation of neurological outcomes after arrest; therefore, reporting the exact deficits of the survivors is a key component

Table 3 Quality review of included studies

Study identification	Confounding*	Participant selection†	Classification of interventions‡	Deviation from intended interventions§	Missing data¶	Outcomes**	Selective reporting††	Overall bias
Alanezi[45] 2004	Serious	Moderate	Low	Moderate	Low	Serious	Moderate	Serious
Barnard[4] 2017	Serious	Moderate	Low	Moderate	Moderate	Moderate	Moderate	Serious
Beck[46] 2016	Moderate	Moderate	Low	Low	Moderate	Moderate	Moderate	Moderate
Calkins[34] 2002	Serious	Low	Low	Low	Low	Serious	Moderate	Serious
Capizzani[35] 2010	Moderate	Low	Low	Low	Low	Serious	Moderate	Serious
Chia[47] 2017	Moderate	Low	Low	Moderate	Low	Moderate	Moderate	Moderate
Chiang[48] 2015	Moderate	Low	Low	Moderate	Low	Moderate	Low	Moderate
Chien[49] 2016	Serious	Low	Low	Low	Moderate	Moderate	Moderate	Serious
David[50] 2007	Moderate	Low	Low	Moderate	Low	Moderate	Moderate	Moderate
Deasy[51] 2012	Moderate	Low	Low	Low	Serious	Moderate	Moderate	Serious
Di Bartolomeo[19] 2005	Serious	Low	Low	Low	Low	Moderate	Moderate	Serious
Djarv[52] 2018	Moderate	Low	Low	Low	Serious	Moderate	Moderate	Serious
Duchateau[53] 2017	Moderate	Low	Low	Low	Low	Moderate	Moderate	Moderate
Evans[44] 2016	Moderate	Low	Low	Low	Moderate	Moderate	Moderate	Moderate
Falcone[54] 1995	Serious	Low	Low	Moderate	Low	Serious	Moderate	Serious
Fisher[55] 1999	Serious	Low	Low	Moderate	Low	Serious	Moderate	Serious
Graesner[56] 2011	Moderate	Low	Low	Moderate	Moderate	Moderate	Moderate	Moderate
Hillman[57] 2016	Serious	Moderate	Low	Moderate	Serious	Serious	Moderate	Serious
Huber-Wagner[58] 2007	Moderate	Moderate	Low	Moderate	Serious	Moderate	Moderate	Serious
Keller[37] 2013	Serious	Serious	Low	Low	Serious	Moderate	Moderate	Serious
Kleber[23] 2014	Serious	Low	Low	Moderate	Low	Moderate	Moderate	Serious
Lawhon[20] 1995	Serious	Low	Low	Low	Low	Serious	Moderate	Serious
Lin[59] 2016	Moderate	Moderate	Low	Low	Low	Moderate	Moderate	Moderate
Love[60] 2016	Moderate	Low	Low	Moderate	Low	Serious	Moderate	Serious
Lundy[61] 2011	Moderate	Moderate	Low	Moderate	Low	Moderate	Moderate	Moderate
Molina[62] 2008	Serious	Low	Low	Low	Low	Serious	Moderate	Serious
Mollberg[63] 2011	Serious	Low	Low	Moderate	Low	Serious	Moderate	Serious
Moore[64] 2011	Moderate	Low	Low	Low	Low	Moderate	Moderate	Serious
Moore[44] 2016	Moderate	Low	Low	Low	Low	Moderate	Moderate	Moderate
Murphy[65] 2010	Serious	Low	Low	Low	Low	Serious	Moderate	Serious
Perron[66] 2001	Moderate	Low	Low	Low	Serious	Moderate	Serious	Serious
Pickens[67] 2005	Moderate	Moderate	Low	Low	Low	Moderate	Moderate	Moderate
Powell[68] 2004	Serious	Serious	Low	Low	Low	Moderate	Moderate	Serious
Rabinovici[69] 2014	Moderate	Low	Low	Low	Low	Serious	Moderate	Serious
Shimazu[70] 1983	Serious	Moderate	Moderate	Low	Low	Serious	Moderate	Serious
Stratton[71] 1998	Moderate	Low	Low	Low	Low	Moderate	Moderate	Moderate
Tarmey[43] 2011	Serious	Low	Low	Moderate	Low	Moderate	Moderate	Serious
Vassallo[72] 2019	Serious	Moderate	Low	Low	Moderate	Moderate	Moderate	Serious
Zwingmann[73] 2015	Moderate	Serious	Low	Low	Low	Moderate	Moderate	Serious
Zwingmann[21] 2016	Moderate	Serious	Moderate	Moderate	Low	Moderate	Moderate	Serious

*Were confounding variables controlled for with statistical analysis (eg, multivariate analysis)? Did they determine these factors appropriately (eg, univariate analysis, references, subject matter expert, etc)?
†Were only survivors/non-vegetative participants assessed? Was any group excluded (eg, specific year of arrests, no rhythm on presentation, type of trauma, witnessed cardiac arrest only, etc)?
‡Was the exposure (traumatic cardiac arrest) well defined before the study? Was there a method used to identify these cases?
§Were special methods used for resuscitation (eg, therapeutic hypothermia, thoracotomy)? If so, was it reported and appropriately accounted for?
¶Were any patients lost to follow-up? Was any method used to account for this/any attempt made to recover from this? Was there a particular group of patients that were lost to follow-up?
**Was the exposure known to the person assessing neurological outcome? How were neurological outcomes assessed? Was it subjective/unclear (eg, physician-reported, self-reported, etc)? Was a standardized scale used and data reported for all categories (eg, Glasgow Outcome Scale)?
††Was there a preregistered protocol with preplanned outcomes to report? Were only specific outcomes reported in full? Were the neurological outcomes dichotomized into "good" and "poor" instead of reporting for each category?

of their neuroprognostication, as there may be a large difference between a moderate disability and a fully recovered patient.

Although the GOS and CPC scales were commonly used, alternatives such as the mRS and the GOSE were not used in any of the included studies. The CPC is heavily weighted toward mental functions and has been criticized for being inadequate to assess functional status at hospital discharge,[25 26] which is supported by significant variability in quality-of-life measures for patients with similar CPC scores.[27 28] Alternatively, the mRS and GOSE scales consider work capacities, social activities, and return to social life.[9 11 29] However, most studies assessed neurological status at discharge, which may be inadequate regardless of the scale used. Most criteria rely on whether patients can perform daily activities, which are not undertaken while in hospital.[11] As cardiac arrest survivors tend to report cognitive impairment and restricted societal participation after hospital discharge,[30] early assessments may overestimate the neurological outcomes. Hence, repeated assessments over time with multiple scales are recommended to accurately assess the functional progression of these patients.

This review has several limitations. To start, our overall neurological outcome may be an overestimate given that patients with moderate deficits and favorable discharge dispositions were assumed to have a favorable outcome. Furthermore, the favorable neurological recovery rate that we provide here is based on a diverse patient population and does not account for the mechanism of trauma (blunt vs. penetrating), the patient age group (adult vs. pediatric), the time point when neurological status is assessed, or special resuscitative techniques. Previous literature has demonstrated varying effects of these factors in neurological outcomes. The effect of the mechanism of injury on traumatic arrest outcomes has been controversial. Whereas some cohort studies suggest that good outcomes can be achieved in select patient groups, especially in those with penetrating injuries,[31 32] other studies suggest that the mechanism of injury is not associated with better outcomes (neurological recovery or survival).[22 33] Hence, it would be valuable to assess the effect of the mechanism of injury on the neurological recovery following arrest. Although only a few studies assess traumatic arrest in the pediatric population, there is a general consensus that the functional outcomes are poorer compared with adults.[15 34 35] In the length of follow-up after cardiac arrest, there is evidence that significant recovery can occur between 1 and 6 months[36] and long-term recovery after 1 year.[37] The majority of the studies we included assessed neurological outcomes at patient discharge or after resuscitation (table 2), suggesting that we underestimated the prevalence of good neurological recovery in the current review. Special resuscitative techniques, such as emergency thoracotomy and therapeutic hypothermia, have some demonstrated benefits in neurological outcomes after traumatic arrest for select patient populations.[38–42] Based on the effects of these factors on neurological recovery, we recommend for future studies evaluating outcomes after traumatic arrest (1) reporting the mechanism of injury for survivors in each neurological outcome category, (2) reporting the age group (adult vs. pediatric) in each neurological outcome category, (3) assessing neurological outcomes 1 year after the arrest if resources allow or >30 days if necessary,[36] and (4) reporting special resuscitative techniques in individual survivors in each neurological outcome category.

Overall, the strength of the scientific evidence for neurological outcomes after TCA is low. Although we identified some large national registry studies, most studies were retrospective cohorts.[4 5 43] Five prospective studies were included, but only one was a multicenter study.[44] Furthermore, our quality assessment revealed a moderate to serious risk of bias in our included studies due to confounding and selective reporting domains. Our outcome of interest was often qualitatively described, and some studies briefly reported neurological outcomes for only one category (eg, vegetative state). As a result, many studies without sufficient data were excluded, and the extent of the selective reporting bias we identified may be an underestimate.

Good and moderate neurological outcomes are frequently reported in patients who survive TCA. However, stronger evidence is needed to prognosticate this patient population as neurological outcomes are often inadequately reported. Future studies should identify and adjust for appropriate confounding variables and report the prevalence of each neurological category. Multicenter prospective studies that focus on the quality of survivorship are urgently needed.

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