American Journal of Emergency Medicine 37 (2019) 5–11

Contents lists available at ScienceDirect

American Journal of Emergency Medicine

journal homepage: www.elsevier.com/locate/ajem

Original Contribution

Early diffusion-weighted imaging and outcome prediction of comatose survivors after suicidal hanging

Dong Won Choi, MD [a], Suk Woo Lee, MD, PhD [a,b], Seong-Hae Jeong, MD, PhD [c], Jung Soo Park, MD, PhD [d], Hoon Kim, MD, PhD [a,b,*]

[a] Department of Emergency Medicine, Chungbuk National University Hospital, 776, Sunhwan-ro, Seowon-gu, Cheongju, Republic of Korea
[b] Department of Emergency Medicine, College of Medicine, Chungbuk National University 1, Chungdae-ro, Seowon-gu, Cheongju, Republic of Korea
[c] Department of Neurology, Chungnam National University Hospital, 282, Munhwa-ro, Jung-gu, Daejeon, Republic of Korea
[d] Department of Emergency Medicine, Chungnam National University Hospital, 282, Munhwa-ro, Jung-gu, Daejeon, Republic of Korea

ARTICLE INFO

Article history:
Received 28 January 2018
Received in revised form 12 April 2018
Accepted 14 April 2018

Keywords:
Diffusion-weighted imaging
Hanging
Early outcome
Cardiac arrest

ABSTRACT

Purpose: Early outcome prediction after suicidal hanging is challenging in comatose survivors. We analysed the early patterns of brain diffusion-weighted magnetic resonance imaging (DWI) abnormalities in comatose survivors after suicidal hanging.
Methods: After suicidal hanging, 18 comatose survivors were prospectively evaluated from January 2013 to December 2016. DWI was performed within 3 h after hanging in comatose survivors. We evaluated Utstein style variables and analysed abnormal spatial profile of signal intensity on DWI, brain apparent diffusion coefficient (ADC) values, and qualitative DWI scores to predict neurological outcomes.
Results: All hanging associated cardiac arrest (CA) patients demonstrated bad neurological outcomes; 80% of non-CA comatose patients experienced good neurological outcomes. In hanging survivors with CA, cortical grey matter structures and deep grey nuclei exhibited profound ADC reductions and high DWI scores within 3 h after hanging, which was associated with diffuse anoxic brain damage with poor cerebral performance categories scores. CA comatose survivors had significantly lower ADC values and higher DWI scores compared to non-CA comatose survivors in the cortex and deep grey nuclei.
Conclusion: Although the presence of CA is the most important clinical prognosticator in hanging-associated comatose survivors, HSI abnormalities and low ADC values in the cortex and deep grey nuclei on DWI performed within 3 h after hanging are well-correlated with unfavourable outcomes regardless of therapeutic hypothermia. Therefore, early DWI may increase the sensitivity of poor outcome prediction and may be an effective combinatorial screening method when available prognostic variables are not reliable or conclusive.

1. Introduction

Hanging is one of the most common methods of attempted suicide worldwide, and hanging-associated cardiac arrest (CA) is a common cause of asphyxial CA in Korea. The suicide rate has remained the highest among the 35 numbers of the Organization for Economic Cooperation and Development for 10 consecutive years, with 29.1 people out of every 100,000 having committed suicide [1]. Although advances in cardiopulmonary resuscitation (CPR) and critical care medicine have considerably increased the survival chances after CA, the neurological prognosis of hanging-associated CA has been shown to be very poor [2,3]. Victims of hanging without CA may present a broad spectrum of injuries, with the most common ones being cervical soft tissue trauma and hypoxic brain damage. The Glasgow Coma Scale (GCS) is the best independent predictor of neurological outcomes in patients admitted for hanging injuries with decreased consciousness but without CA [3,4]. Comatose survivors without CA may demonstrate different functional outcomes in contrast to those with CA. The degree of anoxic brain injury in comatose survivors after hanging needs to be determined as early as possible to plan and perform appropriate post-resuscitation therapy and to counsel family members; however, it can be difficult to estimate their prognosis on admission. Additional tools, including clinical examination, electroencephalogram, somatosensory evoked potentials, neuroimaging, and the measurement of biochemical markers, such as neuron-specific enolase and S-100β protein, have been assessed to predict the neurological outcomes of comatose survivors after hanging. However, there are several limitations in the early accurate prediction of the presence and severity of brain injury encountered by healthcare providers and patients' families after resuscitation from CA [5].

* Corresponding author at: Department of Emergency Medicine, Chungbuk National University 1, Chungdae-ro, Seowon-gu, Cheongju, Republic of Korea.
E-mail address: nichekh2000@chungbuk.ac.kr (H. Kim).

https://doi.org/10.1016/j.ajem.2018.04.027
0735-6757/

In contrast to conventional MRI, diffusion-weighted magnetic resonance imaging (DWI) can reveal acute or early sub-acute findings following a focal ischemic stroke or global cerebral hypoxia. Recently, DWI has been studied as a prognostic modality for comatose survivors after return of spontaneous circulation (ROSC) after CA by identifying hypoxic-ischemic brain injury [6-8]. DWI provides a quantitative value to estimate the severity of brain injury by means of measuring the apparent diffusion coefficient (ADC). If abnormally high signals of DWI are observed in large areas, including the cerebral cortex, basal ganglia, and cerebellum, it suggests devastating diffuse hypoxic-ischemic necrosis with poor clinical prognosis [6]. However, a pattern of DWI abnormality restricted to the basal ganglia or selected cortical regions suggest mild hypoxic brain damage [8]. Preliminary scan studies have shown widespread abnormalities observed on DWI in poor-outcome patients at 1 week or more post CA [8,9]. However, we found no published data on DWI abnormality patterns and DWI usefulness as a prognostic modality in the acute stage (<3 h of hanging) in comatose survivors after suicidal hanging.

Thus, in this study, we analysed the early patterns of DWI and ADC abnormalities within 3 h of hanging in comatose survivors, according to whether CA occurred or not, and determined the prognostic utility of DWI through a clinically applicable qualitative DWI scoring system.

2. Methods

2.1. Study design and population

We received the approval of the institutional review board. All patients were presented to Chungbuk National University Hospital (a university-affiliated, 650-bed hospital in Chungju, Korea) from January 2013 to December 2016. They were prospectively enrolled in the study if they met the following inclusion criteria: age ≥18 years, intentional hanging, comatose state in which a patient is unable to voluntarily open the eyes, unresponsive in spite of strong tactile (painful) or verbal stimuli, and scores between 3 and 8 on the GCS.

2.2. Data acquisition

Patient data were collected from the cardiopulmonary cerebral resuscitation (CPCR) registry, where patient information is registered whenever advanced cardiac life support is provided at our ED. We reviewed and analysed patient medical charts, CPCR registries, and emergency medical services (EMS) records for Utstein style variables. Parameters which were examined are: age; sex; hanging place; hanging time; time from arrest to ROSC; CPR time; GCS at the time of admission; the initial electrocardiogram; laboratory tests including arterial blood gas analysis, complete blood count, and blood chemistry. For imaging studies, we examined the diagnosis of cerebral edema from brain computerized tomography (CT) and fracture on cervical spine from spine CT.

2.3. DWI protocol and imaging processing

All comatose hanging patients with early brain DWIs obtained within 3 h after hanging are included in this study. We excluded those with delayed brain DWIs after 3 h from hanging. MRIs were obtained using a 1.5 T system (Achieva 1.5 T; Philips Medical System, The Netherlands). For DWI, whole-brain axial plane, single-shot spin-echo planar imaging was acquired by applying diffusion-sensitising gradients along three orthogonal directions with a diffusion weighting factor $b = 1000$ s/mm^2 plus one reference scan with $b = 0$. The section thickness was 5 mm and the section gap was 1 mm. In ADC maps, pre-defined regions of interest (ROIs) were manually outlined bilaterally by two independent and blinded investigators in the cortex, corona radiata, internal capsule, hippocampus, pons, caudate, putamen, and thalamus. We calculated the mean and standard deviation (SD) of the ADC value in the outlined ROIs (Fig. 1). Images were assessed by a certified neuroradiologist and an emergency physician. The adjudicators were blinded to patient information, outcome, and readings of other adjudicators.

Images were scored using a DWI scoring system, created to assess the severity of cerebral abnormalities in our previous study [8]. The 10 brain regions were scored using DWI sequences according to the extent and severity of the signal abnormalities on a scale of 0–4. A score of 0, 1, 2, 3, and 4 indicated no abnormality, possible abnormality, mild abnormality, moderate abnormality, and severe abnormality, respectively. T2WI was used to detect old hyperintense abnormalities to exclude chronic infarction, or it was used as a reference image for this study. The presence of abnormal high signal intensity (HSI) in the brain parenchyma was defined by a combination of high DWI and low ADC signal and was distinguished by the same neuroradiologist who did not see the patient information. The MRIs were reviewed on a standard picture archiving and communication system workstation (Maroview; Marotech, Seoul, Korea).

2.4. Outcome

Neurological outcome was assessed using the Glasgow–Pittsburgh Cerebral Performance Categories (CPC) scale at discharge. Good outcome was defined as a CPC score of 1 or 2 and poor outcome was defined as a CPC score of 3, 4, or 5. Scoring was assessed by a trained paramedic coordinator who was blinded to study hypothesis.

2.5. Data analysis

Categorical variables were presented as frequencies and percentages. Comparisons of categorical variables were performed using Chi-squared or Fisher exact tests, as appropriate. Continuous variables were reported as the median and interquartile range (IQR) (non-normal distribution) or the mean and standard deviation (normal distribution). The Mann–Whitney *U* test was conducted for comparisons of two continuous variables. Data were analysed using the PASW/SPSS™ software, version 18 (IBM Inc., Chicago, USA) and GraphPad Prism 5.01 (GraphPad Prism Software, San Diego, CA, USA). A two-sided significance level of 0.05 was used to determine statistical significance.

3. Results

3.1. Patient demographics

During the 4-year study period, a total of 53 patients presented to our emergency department (ED) after a hanging injury (Fig. 2). Of these, 35 patients experienced CA prior to or at the time of ED, and of these, 13 patients experienced restored spontaneous circulation. In 18 non-CA hanging patients, 5 demonstrated comatose mentality on arrival at the ED. As a result, 16 comatose hanging patients underwent DWI imaging (early imaging, 14; delayed imaging, 2). The mean age of hanging patients was 43.4 ± 15.6 years, and 61.0% were male. The most common location where comatose patients were found was their residence (73.2%). All CA hanging patients showed poor outcome and 80% of non-CA hanging comatose patients experienced good outcome (Fig. 2).

3.2. Clinical characteristics of hanging patients

Table 1 shows the comparisons between CA and non-CA groups among comatose hanging survivors who arrived at the ED, and Table 2 presents 14 comatose hanging survivors. Age, sex, the number of witnesses of CA, location, and hanging time were similar in both groups. Arterial blood gas analysis revealed a significant difference in arterial pH (6.9 vs. 7.3, $P = 0.020$), base excess (−20.5 vs. −7.5, $P = 0.006$), and lactic acid (13.8 vs. 7.2, $P = 0.027$) values. Blood chemistry revealed a significant difference in ammonia (204.0 vs. 71.0, $P = 0.011$) value.

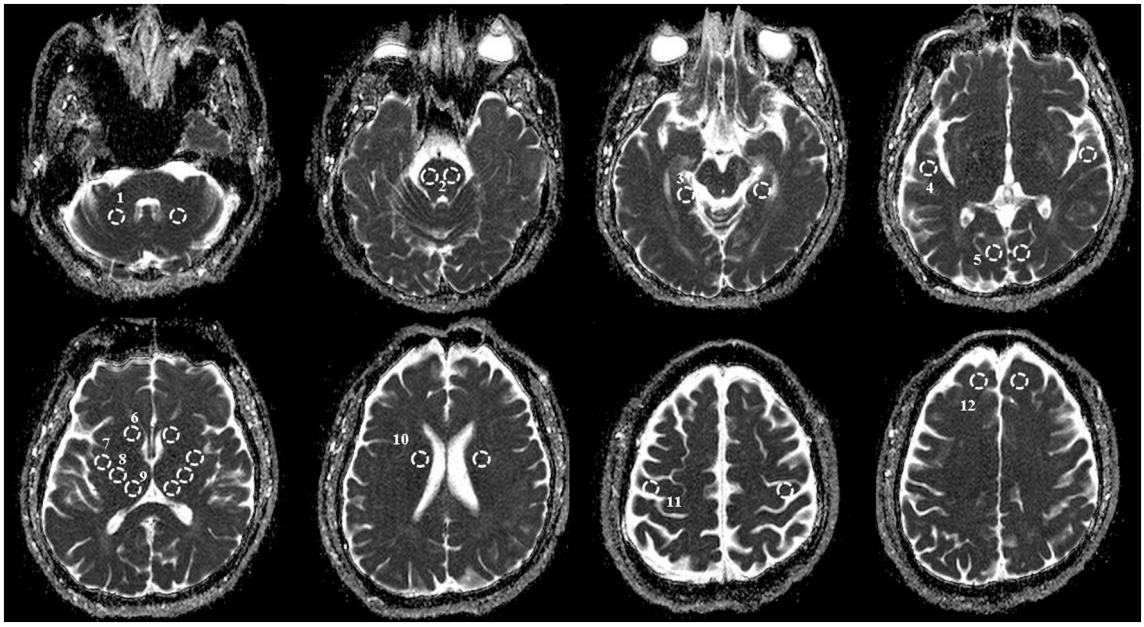

Fig. 1. Pre-defined brain regions of interest manually outlined for apparent diffusion coefficient (ADC) value analyses. These regions were selected for quantitative measurement of the apparent diffusion coefficient values. (1) cerebellum, (2) pons, (3) hippocampus, (4) temporal lobe, (5) occipital lobe, (6) putamen, (7) caudate, (8) internal capsule, (9) thalamus, (10) corona radiata, (11) parietal lobe, (12) frontal lobe.

Among CA hanging survivors, 10 (76.9%) and 2 patients (15.4%) demonstrated asystole and PEA, respectively. All patients underwent cervical spine CT. No patient had a cervical spine fracture, and one patient was diagnosed with a fracture of the temporal styloid process. Eight of 16 comatose survivors who underwent brain CT had cerebral edema. DWI was conducted at 65 min after hanging. Eleven of 18 comatose survivors received therapeutic hypothermia post CA. Only one among hanging patients who suffered OHCA and all non-CA patients were who survived were discharged.

3.3. Qualitative analysis of early DWI in comatose hanging survivors

HSI on early DWI was present in all 10 CA survivors, who showed bad outcomes at discharge. In the non-CA comatose hanging group, 1 patient demonstrated no HSI on early DWI but demonstrated HIS on delayed DWI, with bad outcomes at discharge. Three (75%) patients had negative high signal and demonstrated good outcomes at discharge. Interestingly, 1 patient with right middle cerebral infarction on early DWI was excluded from our study because of alert mentality on arrival at the ED (Fig. 3B). Early DWI of CA patients showed diffuse signal abnormalities in the cortex in both hemispheres, frontal and parietal lobes, cerebellum, thalamus, and hippocampus (Fig. 3A). As shown in Table 3, the average DWI scores of CA comatose patients in the cortical grey matter structures and deep grey nuclei were 3.9 (3.3, 4.0) and 3.0 (2.8, 3.5), respectively. The average DWI scores of non-CA comatose hanging patients in the cortical grey matter structures and deep grey nuclei were 1.0 (1.0, 1.0) and 1.0 (1.0, 1.0), respectively. There was a significant difference between the two groups ($P < 0.005$) (Table 3).

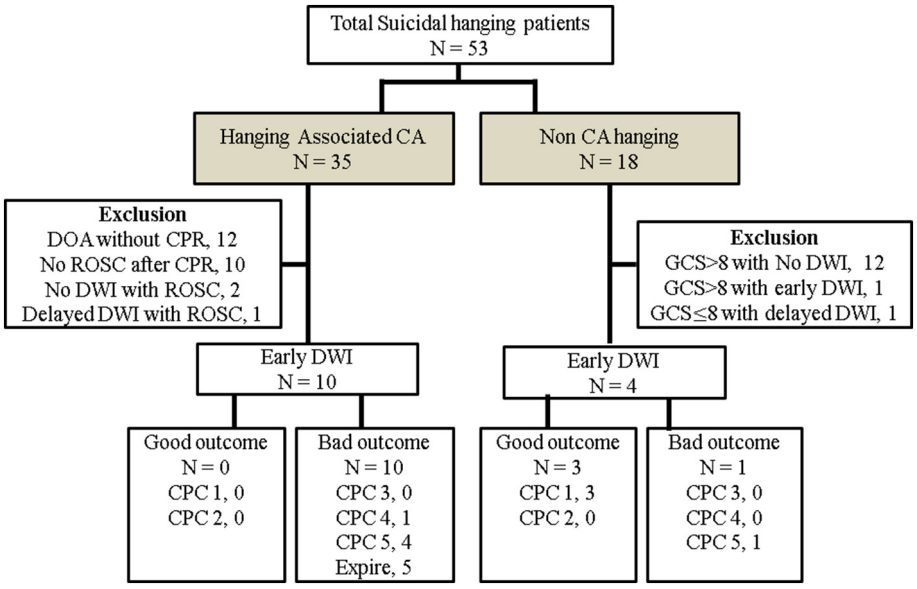

Fig. 2. The number and neurological outcome of suicidal hanging patients. CA, cardiac arrest; DWI, diffusion weight magnetic resonance imaging ROSC, return of spontaneous circulation; DOA, death on arrival; CPR, cardiopulmonary resuscitation; CPC, cerebral performance category.

Table 1
The clinical characteristics of the 18 comatose survivors after suicidal hanging

Characteristics	Cohort	CA	Non-CA	*p*-value
Patients, n (%)	18	13 (72.2)	5 (27.8)	
Age, year, median, (IQR)	45.5 (36.8, 53.3)	46.0 (21.0,55.5)	45.0 (41.0, 60.5)	0.702
Sex, male, n (%)	12 (66.7)	8 (61.5)	4 (80.0)	0.600
Location				0.603
Place of residence, n (%)	12 (66.7)	9 (69.2)	3 (60.0)	
Public place, n (%)	1 (5.5)	1 (7.7)	0 (0.0)	
Others, n (%)	5 (27.8)	3 (23.1)	2 (40.0)	
Hanging time (min), n (%)				0.345
≤10	2 (11.1)	1 (7.7)	1 (20.0)	
>10	7 (38.9)	6 (46.2)	1 (20.0)	
Unknown	9 (50.0)	6 (46.2)	3 (60.0)	
Time from EMS call to ED arrival, min, median, (IQR)	23.0 (14.5, 32.5)	23.0 (14.5, 32.5)		
Time from arrest to ROSC, min, median, (IQR)	32.0 (26.0, 48.0)	32.0 (26.0, 48.0)		
CPR time (min)				
Out of hospital	20.0 (15.0, 28.0)	20.0 (15.0, 28.0)		
In hospital	6.5 (2.0, 22.25)	6.5 (2.0, 22.25)		
Total	31.0 (24.0, 40.6)	31.0 (24.0, 40.6)		
Initial GCS after ROSC				0.109
3, n (%)	17 (94.4)	13 (100.0)	4 (80.0)	
≤4, n (%)	1 (5.6)	0 (0.0)	1 (20.0)	
Initial rhythm				
VF/pulseless VT, n (%)	0 (0.0)	0 (0.0)		
PEA, n (%)	2 (15.4)	2 (15.4)		
Asystole, n (%)	10 (76.9)	10 (76.9)		
Unknown, n (%)	1 (7.7)	1 (7.7)		
ABGA, median, (IQR)				
pH	7.0 (6.8, 7.3)	6.9 (6.8,7.1)	7.3 (7.1, 7.3)	0.020
pCO_2 (mmHg)	56.0 (35.3, 89.5)	80.7(32.1. 100.5)	48.8(35.1, 62,3)	0.206
pO_2 (mmHg)	65.8 (26.7, 87.9)	55.7 (14.8, 107.9)	78.2 (52.8, 87.9)	0.922
Base excess (mmol/L)	−28.8 (−23.0,-9.8)	−20.5 (−25.1, −15.8)	−7.5 (−15.0,-4.7)	0.006
Lactic acid (mmol/L)	13.0 (7.3, 17.0)	13.8 (11.4, 18.8)	7.2 (4.0, 11.7)	0.027
CBC & Chemistry, median, (IQR)				
Ammonia (ug/dL)	132.0 (70.5, 227.0)	204.0 (97.5, 260.0)	71.0 28.9, 94.5	0.011
CRP (mg/dL)	0.1 (0.1, 0.3)	0.1 (0.1, 0.3)	0.1 (0.1, 0.3)	0.565
WBC($\times 10^3$/uL)	11.1 (9.3, 15.9)	10.2 (9.1, 15.4)	12.1 (9.5, 19.7)	0.852
CK (IU/L)	142.0 (109.0, 225.3)	166.0 (114.0, 228.5)	109.0 (78.5, 206.5)	0.522
CK-MB (ng/mL)	2.0 (1.2, 5.1)	2.4 (1.5, 5.2)	1.0 (0.7, 4.0)	0.446
Troponin T (pg/mL)	0.0 (0.0, 0.0)	9.0 (7.0, 15.0)	6.0 (3.5, 17.5)	0.507
Cortisol (ug/dL)	13.3 (7.3. 30.1)	13.3 (7.3. 30.1)		
NSE (ng/ mL)	55.5 (29.6, 139.2)	55.5 (33.9, 148.2)		
Fracture on C - spine CT, n (%)	0/18 (0.01)	0/13 (0.0)	0/5 (0.0)	1.000
Cerebral edema on brain CT, n (%)	8/16 (50.0)	7/12 (58.3)	1/4 (25.0)	0.278
From hanging to Brain DWI, min, median, (IQR)	65.0 (20.0, 114.3)	82.5 (42.6. 114.3)	58.5 (28.0, 107.0)	0.437
Therapeutic hypothermia, n (%)	11/18	6/13 (46.2)	5/5 (100.0)	0.037
Survival to discharge, n (%)	6/18 (33.3)	1/13 (7.7)	5/5 (100.0)	<0.001

CA, Cardiac arrest; ROSC, Return of spontaneous circulation; CPR, Cardiopulmonary resuscitation; ED, Emergency department; ROSC, Return of spontaneous circulation; GCS, Glasgow Coma Scale score; CBC, Complete blood count; CRP, C-reactive protein; CPK, Creatine kinase; CK-MB, Creatine kinase MB isoenzyme; CT Computerized tomography; C – spine; Cervical spine; GCS, Glasgow coma scale; DWI, Diffusion weight magnetic resonance imaging; *p-value means statistical comparisons between CA and Non-CA group.

Table 2
Overview of hanging associated comatose survivors to hospital admission (Case 1–10, hanging associated CA patients; Case 11–14, hanging associated non-CA patients)

Case No	Age (yr)	Sex	Location	Hanging Time (min)	Arterial pH	Base excess (mmol/L)	Lactic acid (mmol/L)	Ammonia (ug/dL)	NSE (ng/ml)	Fracture on cervical spine CT	Brain CT	DWI Time (min)	DWI	TH	Hospital Stay (days)	CPC
1	64	M	R	≤10 min	6.89	−24.6	12.8	204	–	N	Edema	165	Ischemia	N	12	expire
2	75	M	R	>10 min	6.78	−22.3	18	224	–	N	Normal	42	Ischemia	N	1	4
3	50	F	R	>10 min	6.77	−26.4	19	230	–	N	Edema	118	Ischemia	N	1	5
4	51	M	R	>10 min	6.78	−25.6	20	–	–	N	Normal	103	Ischemia	Y	6	expire
5	30	M	other	>10 min	6.87	−16.3	16	204	25.33	N	Normal	65	Ischemia	Y	11	expire
6	41	F	R	unknown	7.31	−15.3	10.9	70	159.4	N	Edema	61	Ischemia	Y	26	5
7	46	F	R	>10 min	6.99	−10.4	10.4	132	36.69	N	Normal	41	Ischemia	N	6	5
8	27	F	R	unknown	6.88	−22.4	13.8	270	60	N	Edema	100	Ischemia	N	1	expire
9	21	M	other	unknown	7.10	−18.5	13.7	358	51.08	N	Edema	37	Ischemia	Y	5	expire
10	60	M	other	unknown	7.12	−19.1	13	86	–	N	Edema	113	Ischemia	N	1	expire
11	38	M	R	unknown	6.91	−22.1	16	105	123.7	N	Edema	121	Normal	Y	46	5
12	51	M	R	unknown	7.23	−7.5	7.4	71	27.25	N	Normal	56	Normal	Y	8	1
13	44	M	other	>10 min	7.32	−7.8	7.2	84	–	N	Normal	40	Normal	Y	4	1
14	70	M	R	unknown	7.32	−2.8	3.7	51	–	N	Normal	52	Normal	Y	12	1

CPR, Cardiopulmonary resuscitation; R, Place of residence; P, Public place; CT, Computerized tomography; DWI, Diffusion weighted magnetic resonance imaging; DWI time, Time from hanging to Brain DWI; GHIE, Global hypoxic ischemic encephalopathy; TH, Therapeutic hypothermia; CPC, cerebral performance category at discharge; HCD, herniated cervical disc; ROSC, Return of spontaneous circulation; NSE, Neuron specific enolase.

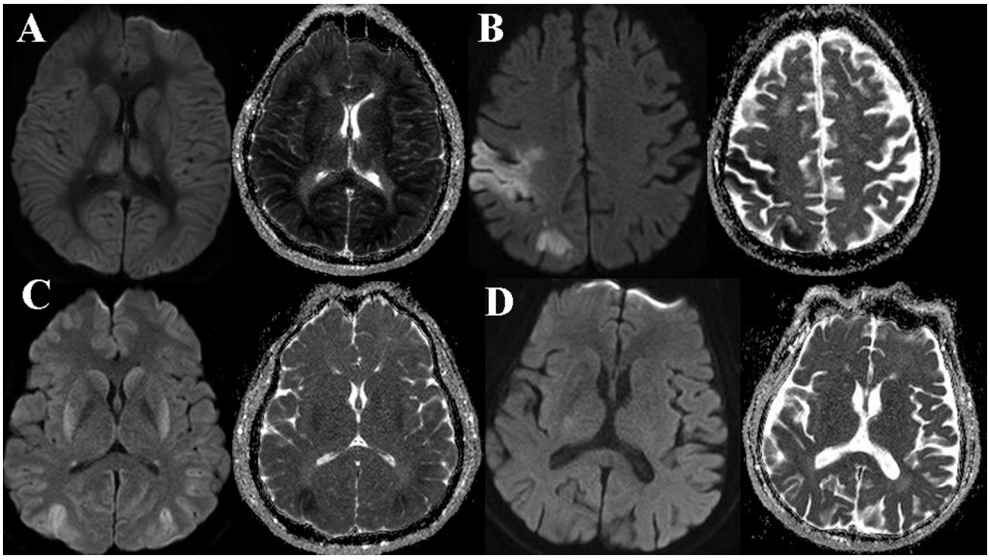

Fig. 3. Representative brain DWI and corresponding ADC map within 3 h after hanging. (A) DWI of Case 1 (CA patient) in Table 2 showing diffuse high signal in the cortex and low signal in the corresponding ADC map. (B) DWI of non-CA patient showing the acute infarctions on left middle cerebral artery territory with low signal in ADC maps at the same levels. (C) DWI of case 12 (non-CA patient) in Table 2 showing the multifocal acute infarctions with low signal in ADC maps at the same levels. (D) DWI of case 14 (non-CA patient) in Table 2 showing normal findings.

3.4. Qualitative analysis of the ADC values in comatose hanging survivors

ADC mapping and quantification are shown in Table 3. Normal values are 700–800 $\times 10^{-6}$ mm^2/s; decreased ADC values represent areas of restricted diffusion, presumably because of infarction. ADC values were measured in 14 patients: 11 had unfavourable outcomes and 3 had favourable outcomes. In CA patients (average ADC value, $582 \pm 45 \times 10^{-6}$ mm^2/s), the thalamus showed the lowest mean ADC value ($521 \pm 105 \times 10^{-6}$ mm^2/s), while the temporal cortex had the highest mean ADC value ($641 \pm 88 \times 10^{-3}$ mm^2/s). None of the CA patients recovered beyond a severely disabled state. The average ADC value of non-CA patients was $727 \pm 81 \times 10^{-6}$ mm^2/s. The CA group had significantly different mean ADC values than the non-CA group in the frontal, parietal, temporal, occipital, thalamus, caudate nucleus, putamen, hippocampus, pons, putamen, and cerebellum ($P < 0.05$). One non-CA patient had normal MR images on early DWI, but he experienced abnormalities 48 h after early DWI.

4. Discussion

For comatose patients after hanging, understanding of the outcomes by the physicians, who are required to make medical decisions concerning their disposal, is important. Our data suggest that the pattern of brain injury on early DWI (<3 h after hanging) and quantitative measurements of regional ADC may help predict the clinical outcomes of comatose survivors after hanging.

DWI detects early cytotoxic edema by measuring the random motion of water protons, a process that is reduced by failure of the energy-requiring active water transport mechanism [7,10]. Therefore, it can show restricted diffusion associated with acute ischemia within 30 min after acute stroke. However, there are limited data available on its utility in comatose patients with global ischemic brain injury 5 days [6], 7 days [9], 15 days [11] after resuscitation or at a median (IQR) of 80 h (55–117) after CA [7]. Additionally, there is no study on its usefulness as an early prognostic predictor in comatose survivors

Table 3
The ADC (apparent diffusion coefficient) values and Qualitative DWI scores in the individual brain regions in the patients (mean ADC; $\times 10^{-6}$ mm^2/s).

Case no	Quantification apparent diffusion coefficient mapping													DWI scores		
	Frontal lobe	Parietal lobe	Temporal lobe	Occipital lobe	Corona radiata	Thalamus	Internal capsule	Caudate	Putamen	Hippoc ampus	Pons	Cerebe llum	Ave	Cortex (24)	DGN (16)	Total (40)
1	349	350	328	352	289	328	645	299	240	365	577	322	370	24	16	40
2	605	611	635	595	631	533	455	625	692	520	623	568	591	22	9	31
3	771	564	685	543	582	485	724	411	420	428	624	590	569	23	14	37
4	605	648	662	615	647	560	635	657	658	518	636	668	626	20	12	32
5	286	281	721	648	604	485	680	659	372	554	585	578	538	19	11	30
6	639	648	701	550	596	703	632	669	577	696	639	601	638	24	12	36
7	675	629	601	519	652	583	576	669	583	627	586	528	602	24	14	38
8	688	495	650	515	622	–	–	–	–	–	–	–	594	24		
9	588	441	419	328	536	318	691	571	508	512	631	317	488.	24	13	37
10	672	676	696	617	633	499	687	700	730	667	582	651	596	19	16	25
Ave	614	555	641	548	611	521	635	620	485	565	613	563	582	22	13	33
11	786	756	727	731	677	814	717	762	815	838	702	689	751	6	4	10
12	718	719	731	711	616	742	755	715	701	638	624	616	691	6	4	10
13	750	689	747	699	579	636	626	721	663	710	716	655	683	6	4	10
14	848	774	868	792	778	769	720	734	899	794	733	700	784	6	4	10
Ave	776	735	768	733	663	740	705	733	770	745	694	665	727	6	4	10
p value	0.030	0.003	0.003	0.002	0.374	0.004	0.199	0.003	0.020	0.011	0.022	0.020	0.002	0.001	0.003	0.003

Case 1–10, hanging associated CA patients; Case 11–14, hanging associated non-CA patients; DGN, Deep grey nuclei.

after hanging [6-9,12]. In our study, DWI was conducted within 2.5 h after arrival at the ED, and cerebral diffusion abnormalities in diffuse brain area, including cortical areas, basal ganglia, and cerebellum, were observed in all hanging-associated CA survivors, which was associated with poor neurological outcomes. We assumed that the diffuse HIS on DWI scanning immediately after resuscitation may be significant in predicting poor neurological outcome from hanging-associated CA survivors. Clinical literature has showed that hanging-associated CA demonstrated low rate of ROSC and poor neurological outcomes at discharge compared to OHCA from cardiac aetiology [2,13]. Severe hypoxic - ischemic injury in hanging induced CA could be related to the long duration of critical abruptness of the anoxic insult more than that in non-asphyxial CA.

Hanging patients without CA presented a broad spectrum of DWI findings, such as normal, focal high signal density, and mixed pattern of injury (cortex and deep grey nuclei). Three comatose patients with normal early DWI findings have good outcomes, but one case with normal early DWI findings showed diffuse HSI in delayed DWI and had poor outcomes. Because of the small number of patients, we were unable to determine the prognostic power of DWI in the early stage after hanging without CA; however, the pattern on early DWI could help to predict the outcome of hanging patients without CA. Depending on the time of suspension, the patient may experience cerebral hypoxia and ischaemia with different severity. Wee JH, et al., [4] reported that a total of 21 hanging patients with decreased consciousness but without CA had an initial GCS score between 3 and 11, and all regained consciousness spontaneously without receiving therapeutic hypothermia and were discharged with cerebral performance category 1. In contrast, other studies demonstrated that 7.5% of non-CA hanging patients with altered mentality showed bad outcomes [13]. In our 5 comatose patients with a GCS score of 8 or less, 1 patient was discharged with cerebral performance category 5, despite receiving therapeutic hypothermia. As an interesting case of hemodynamic stroke caused by strangulation from suicidal hanging, the patient presented with a left hemiparesis with grade III motor deficit. DWI revealed an ischemic stroke on the region of the right distal middle cerebral artery. There was no evidence of injury to cervical vessels. There were two case reports on hemodynamic stroke secondary to manual strangulation [14,15].

Together with the high cortical signal of DWI, a marked ADC decrease in the early phase of global cerebral hypoxia correlates with irreversible tissue injury or cortical laminar necrosis, and it may be an early marker of the clinical outcome [6,11,16]. Recent studies reported quantitative ADC analyses of the whole brain or regional brain as a significant prognostic tool for predicting poor outcomes in comatose survivors after CA [6,9].

The reported normal ADC values in the grey matter and white matter were 780 to 1090 $\times 10^{-6}$ mm^2/s and 620 to 790 $\times 10^{-6}$ mm^2/s, respectively [17]. In all patients with CA, the ADC values were significantly decreased compared to those in non-CA hanging patients, and the reported normal DWI value within 3 h after hanging led to poor outcome (CPC 5) at discharge. All of them showed a mean ADC value of 582 $\times 10^{-6}$ mm^2/s in the 12 pre-defined brain regions. Thus, hanging-associated CA patients have a high tendency to report low ADC values in early DWI, which have prognostic poor outcomes, despite receiving therapeutic hypothermia.

TH has been known to improve the survival and neurological outcomes of CA survivors, but its effect on hanging-associated CA is unclear [18,19]. Recent case reports and small retrospective studies have suggested that TH may lead to beneficial neurological outcomes in adult survivors who sustained asphyxial CA [20-22]. Cindy H et al., [23] reported that there were no significant differences between the overall survival and patients discharged with good neurological outcome between the therapeutic hypothermia and non- therapeutic hypothermia CA groups after hanging. Of 13 CA patients, 6 received therapeutic hypothermia but all patients showed poor outcomes, despite receiving therapeutic hypothermia. However, a multi-centre retrospective study is required to determine the impact of therapeutic hypothermia on the outcomes of hanging-associated CA because the patients size in our study was small.

Our previous results derived from a prospective study of 19 patients, indicate that qualitative brain DWI scores may be a useful adjunct in the prediction of neurological outcomes for comatose OHCA patients in early phase after CA [8]. At 100% specificity, the overall, cortex and cortex plus deep grey nuclei scores predicted poor patient outcomes with a sensitivity of 91.7–100% (95% CI). There was a significant difference of the average DWI scores in the cortical grey matter structures and deep grey nuclei between the good outcome and bad outcome groups.

However, our study had some limitations. First, the study involved a small number of patients since the study was conducted at a single centre, because the incidence comatose survivors from suicidal hanging are rare. Second, it was difficult for the physician to obtain precise information to include in the medical record in an emergency situation; therefore, there are some missing variables, such as hanging time, height of hanging, hanging type, and hanging mark. Third, we did not follow-up DWI among the patients. Finally, the neurological outcomes in our study were based on the CPC score at the time of hospital discharge, which may differ from the long-term neurological outcomes.

5. Conclusions

The presence of CA is the most important clinical prognosticator in hanging patients. Our study demonstrated that HSI abnormalities and low ADC values in the cortex and deep grey nuclei on DWI performed within 3 h after hanging are well-correlated with unfavourable outcomes regardless of therapeutic hypothermia. The recognition of brain injury pattern using DWI and ADC may be important to predict clinical outcome of OHCA hanging patients. Additionally, quantitative measurement of DWI scores in the cortex and deep grey nuclei may help in distinguishing an unfavourable outcome from a favourable outcome in comatose hanging patients. Therefore, early DWI may increase the sensitivity of poor outcome prediction and may be an effective combinatorial screening method when available prognostic variables are not reliable or conclusive.

Conflict of interest statement

The authors have no conflict of interest to report.

Acknowledgements

This research was supported by the Basic Science Research Program through the National Research Foundation of Korea funded by the Ministry of Education, Science and Technology (2015R1A2A2A01002303 & NRF-2016R1D1A1B04930247).

References

[1] Roh S, et al. Mental health services and R&D in South Korea. Int J Ment Health Syst 2016;10:45.
[2] Wee JH, et al. Outcome analysis of cardiac arrest due to hanging injury. Am J Emerg Med 2012;30(5):690–4.
[3] Martin MJ, et al. Patterns of injury and functional outcome after hanging: analysis of the National Trauma Data Bank. Am J Surg 2005;190(6):836–40.
[4] Wee JH, et al. Outcomes of patients admitted for hanging injuries with decreased consciousness but without cardiac arrest. Am J Emerg Med 2013;31(12):1666–70.
[5] Taccone F, et al. How to assess prognosis after cardiac arrest and therapeutic hypothermia. Crit Care 2014;18(1):202.
[6] Choi SP, et al. Diffusion-weighted magnetic resonance imaging for predicting the clinical outcome of comatose survivors after cardiac arrest: a cohort study. Crit Care 2010;14(1):R17.
[7] Mlynash M, et al. Temporal and spatial profile of brain diffusion-weighted MRI after cardiac arrest. Stroke 2010;41(8):1665–72.
[8] Park JS, et al. Efficacy of diffusion-weighted magnetic resonance imaging performed before therapeutic hypothermia in predicting clinical outcome in comatose cardiopulmonary arrest survivors. Resuscitation 2015;88:132–7.

[9] Wijman CA, et al. Prognostic value of brain diffusion-weighted imaging after cardiac arrest. Ann Neurol 2009;65(4):394–402.
[10] Stanziano M, et al. Post-anoxic vegetative state: imaging and prognostic perspectives. Funct Neurol 2011;26(1):45–50.
[11] Wijdicks EF, Campeau NG, Miller GM. MR imaging in comatose survivors of cardiac resuscitation. AJNR Am J Neuroradiol 2001;22(8):1561–5.
[12] Els T, et al. Diffusion-weighted MRI during early global cerebral hypoxia: a predictor for clinical outcome? Acta Neurol Scand 2004;110(6):361–7.
[13] Kim MJ, et al. Neurologic outcome of comatose survivors after hanging: a retrospective multicenter study. Am J Emerg Med 2016;34(8):1467–72.
[14] Neto HS, et al. Hemodynamic stroke caused by strangulation. Int J Clin Exp Med 2014;7(9):2932–5.
[15] Ikenaga T, et al. Unilateral dissection of the cervical portion of the internal carotid artery and ipsilateral multiple cerebral infarctions caused by suicidal hanging: a case report. No Shinkei Geka 1996;24(9):853–8.
[16] McKinney AM, et al. Diffusion-weighted imaging in the setting of diffuse cortical laminar necrosis and hypoxic-ischemic encephalopathy. AJNR Am J Neuroradiol 2004;25(10):1659–65.
[17] Helenius J, et al. Diffusion-weighted MR imaging in normal human brains in various age groups. AJNR Am J Neuroradiol 2002;23(2):194–9.
[18] Soar J, et al. Part 4: advanced life support: 2015 international consensus on cardiopulmonary resuscitation and emergency cardiovascular care science with treatment recommendations. Resuscitation 2015;95:e71–120.
[19] Nolan JP, et al. Part 1: executive summary: 2015 international consensus on cardiopulmonary resuscitation and emergency cardiovascular care science with treatment recommendations. Resuscitation 2015;95:e1–31.
[20] Baldursdottir S, et al. Induced hypothermia in comatose survivors of asphyxia: a case series of 14 consecutive cases. Acta Anaesthesiol Scand 2010;54(7):821–6.
[21] Lee BK, et al. Outcome and adverse events with 72-hour cooling at 32 degrees C as compared to 24-hour cooling at 33 degrees C in comatose asphyxial arrest survivors. Am J Emerg Med 2014;32(4):297–301.
[22] Wee JH, et al. Outcomes of asphyxial cardiac arrest patients who were treated with therapeutic hypothermia: a multicentre retrospective cohort study. Resuscitation 2015;89:81–5.
[23] Hsu CH, et al. Outcome of suicidal hanging patients and the role of targeted temperature management in hanging-induced cardiac arrest. J Trauma Acute Care Surg 2017;82(2):387–91.