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Prognostic Value of Brain Diffusion Weighted Imaging After Cardiac Arrest

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Abstract

Objective—Outcome prediction is challenging in comatose post-cardiac arrest survivors. We assessed the feasibility and prognostic utility of brain diffusion-weighted MRI (DWI) during the first week.

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Methods—Consecutive comatose post-cardiac arrest patients were prospectively enrolled. MRI data of patients who met predefined specific prognostic criteria were used to determine distinguishing ADC thresholds. Group 1: death at 6 months *and* absent motor response or absent pupillary reflexes *or* bilateral absent cortical responses at 72 hours, *or* vegetative at 1 month. Group 2A: Glasgow outcome scale (GOS) score of 4 or 5 at 6 months. Group 2B: GOS of 3 at 6 months. The percentage of voxels below different apparent diffusion coefficient (ADC) thresholds was calculated at $50 \times 10^{-6} \text{ mm}^2/\text{sec}$ intervals.

Results—Overall, 86% of patients underwent MR imaging. Fifty-one patients with 62 brain MRIs were included in the analyses. Forty patients met the specific prognostic criteria. The percentage of brain volume with an ADC value below $650\text{--}700 \times 10^{-6} \text{ mm}^2/\text{sec}$ best differentiated between group 1 and groups 2A and 2B combined ($p < 0.001$), while the $400\text{--}450 \times 10^{-6} \text{ mm}^2/\text{sec}$ threshold best differentiated between groups 2A and 2B ($p = 0.003$). The ideal time window for prognostication using DWI was between 49 to 108 hours after the arrest. When comparing MRI in this time window with the 72 hour neurological examination MRI improved the sensitivity for predicting poor outcome by 38% while maintaining 100% specificity ($p = 0.021$).

Interpretation—Quantitative DWI in comatose post-cardiac arrest survivors holds great promise as a prognostic adjunct.

Approximately 350,000 cardiac arrests occur annually in the United States¹. Up to half of these patients are successfully resuscitated. In the past, only 10% to 30% of comatose post-cardiac arrest patients had good functional recovery. These numbers will likely improve with the increasing use of therapeutic hypothermia^{2,3}.

Post-cardiac arrest brain injury is a common cause of morbidity and mortality. Many comatose post-cardiac arrest patients die or survive with severe disability after a prolonged intensive care unit stay associated with a tremendous cost burden^{4,5}. Conversely, the potential for premature withdrawal of life support from patients who may have a chance of functional recovery represents an additional ethical dilemma. Thus, early accurate identification of patients who have no likelihood of meaningful recovery is a very important health care issue.

Although several prognostic variables have been studied in comatose post-cardiac arrest patients, the currently accepted variables (neurological examination, neurophysiologic tests, and serum markers) have substantive limitations. First, they identify only a subset of poor outcome patients with high specificity. Second, the neurological examination and the results of electroencephalography may be difficult to interpret in the presence of sedative agents or metabolic derangements and third, serum markers are potentially susceptible to false-positive test results and not yet readily available in many hospitals^{6,7}. Moreover, these variables have not been validated in patients who undergo induced hypothermia.

Recent developments in brain MRI, in particular diffusion-weighted MRI (DWI), provide a new and potentially powerful marker of early global ischemic brain injury. Preliminary studies have shown widespread DWI abnormalities in poor outcome post-cardiac arrest patients during the first week⁸. However, obtaining a brain MRI in critically-ill patients with potential cardiac instability may be challenging⁹. The overall aim of this study was to determine the feasibility and prognostic utility of quantitative DWI MRI in a prospective series of comatose post-cardiac arrest patients.

METHODS

Patients

Consecutive post-cardiac arrest patients who remained comatose following successful resuscitation were prospectively enrolled over a 4-year time period. During this time, the neurocritical care team was notified of all cardiac arrest admissions and patients were evaluated for study participation within 1 hour after restoration of spontaneous circulation. In addition, the adult intensive care and coronary care units were screened on weekdays for potentially eligible patients.

Patients were enrolled provided they met the following inclusion criteria: age 18 years or older; status post resuscitation for in- or out-of-hospital cardiac arrest; persistent coma defined as: no eye opening to voice and inability to follow commands. Exclusion criteria were: pre-existing “do not resuscitate” status or modified Rankin Scale (mRS) score ≥ 3 ; severe coexisting systemic disease with a limited life expectancy; inability to undergo MRI due to a metallic object in the body; pregnancy; and brain death. The study was approved by the institutional review board and written consent from a legally authorized representative was required for study participation.

Clinical and neurophysiologic studies were obtained in a prospective and standardized fashion at predefined time points. Neurological examinations (including a Glasgow coma scale score and an assessment of brainstem function) were performed daily during the first 3 days and at 1 and 2 weeks following cardiac arrest. Somatosensory evoked potentials (SSEPs) and a routine EEG were obtained at 72 ± 8 hours following resuscitation. Guidelines for treatment limitations and withdrawal of life support were provided by the on-service neurocritical care team and consistent with the 2006 American Academy of Neurology practice parameter.⁷ Decision-making regarding aggressiveness of care and withdrawal of life support was considered to be the responsibility of the treating clinical team and not the investigators of the study.

Functional outcome after 1, 3, and 6 months was determined by means of the Glasgow Outcome Scale (GOS) score utilizing a standardized telephone interview. In addition, when feasible, patients were evaluated at 6 months in the neurology clinic and underwent a neuropsychological test battery at this time.

One or more MRI examinations were planned within the first week after the arrest if the treating physicians felt that the patient could safely undergo MRI during this time. Reasons for not obtaining the MRI and any adverse events during transport to or from the MRI suite, or during acquisition of the MR images were documented. The treating physicians had access to the MRI images and the radiology reports, but they were not informed of the results of the quantitative MRI analysis. MRIs were obtained after return to normal body temperature in patients who were treated with induced hypothermia.

A treatment protocol for the use of hypothermia in comatose post-cardiac arrest survivors was adopted at our hospital during the conduct of this study. Eligible patients underwent hypothermia for 24 hours with a target temperature of 33°C using either surface or catheter based cooling technologies. It has been shown that ADC values change linearly and directly with lowering brain temperatures (approximately 1.6% change in ADC with 1°C change in brain temperature).¹⁰ Because brain MRIs were obtained after return to normal body temperature correction of ADC values for hypothermia was not indicated.

MRI Parameters and Image Processing

All patients with technically adequate brain DWI MRIs obtained within 7 days after the arrest are included in this report. Twenty to 23 contiguous DWI sections per patient were acquired using a 1.5T GE Signa Horizon scanner (GE Medical Systems, Waukesha, WI). Images were acquired with spin echo echo-planar imaging (SE EPI DWI) 256×256 matrix, field of view 24×24 cm, slice thickness/gap 5/1.5 or 5/2.5 mm, X, Y, Z axes averaged, $b=0$ and 1000 sec/mm^2 . Images were processed and analyzed on a PC using a Diffusion/Perfusion Analysis program (UCLA Stroke Center, Stanford Stroke Center) written in IDL programming language (Research Systems, Inc., Boulder, CO), which creates absolute diffusion coefficient (ADC) maps for each brain image slice. Using a cursor, investigators outlined the brain on each slice. The program saved all outlined regions of interest (ROI) and produced spreadsheets containing ADC values of each voxel in the ROI. The total brain volume, the mean brain ADC value, and the percentage of voxels below different ADC thresholds were calculated. MRI analyses were performed by two independent investigators who were not familiar with the patients or each other's measurements.

Patients included in the analyses to determine distinguishing ADC thresholds associated with prognosis

MRI data of patients meeting criteria of one of three prespecified groups were used to determine distinguishing ADC thresholds associated with prognosis. Group 1: dead or vegetative at 6 months *and* absent motor response or pupillary reflexes at 72 hours in the absence of sedating medications, *or* vegetative at 1 month, *or* bilateral absent cortical responses. Group 2A: Glasgow outcome scale (GOS) score of 4 or 5 at 6 months. Group 2B: GOS of 3 at 6 months. Mean brain ADC values and the percentage of voxels below different apparent diffusion coefficient (ADC) thresholds were calculated. Patients who died without meeting the highly specific clinical criteria for poor outcome defined above for group 1 because of (potentially premature) withdrawal of life support or a cardiopulmonary complication (for example a second cardiac arrest) were not included in these analyses. Some patients were taken off life support without meeting highly specific criteria for poor outcome from a neurological standpoint, for example because of advanced age, or because of comorbidities or a poor quality of life at baseline. The rationale for excluding these patients from the quantitative DWI analyses was to avoid the inclusion of patients who were taken off life support early and potentially prematurely because of a perceived poor functional outcome, but without great certainty on whether or not they would have done poorly with continued life support in the long-term.

Data Analysis

To determine the optimal ADC thresholds associated with prognosis we analyzed the first brain MRI only. ADC thresholds were analyzed from 300 to $1000 \times 10^{-6} \text{ mm}^2/\text{sec}$ at $50 \times 10^{-6} \text{ mm}^2/\text{sec}$ intervals. Both the mean brain ADC values and the percentage of voxels below different ADC thresholds were determined. The difference between groups was evaluated at each threshold and the most distinguishing one was identified. Using ROC analysis, the cutoff predicting outcome with 100% specificity was estimated for the percentage of the brain volume below the most distinguishable ADC threshold. Group comparisons were made between groups 1 and groups 2A and 2B combined and between groups 2A and 2B. Brain MRIs of 15 patients who had suffered a temporary neurologic deficit of unclear cause and who had returned to normal were used as controls. These patients had normal brain MRIs without DWI abnormalities and without substantive chronic ischemic lesions..

To identify the ideal time window for prognostication with DWI during the first week we determined the moving average of the percentage of brain volume below the identified ADC

threshold in survivors versus patients who died (or remained vegetative) including all MRIs of all patients. Lastly, for the comparison of the prognostic value of DWI with the neurological examination at 72 hours, we included all patients with MRIs during the identified optimal time window.

Statistical analyses were performed using SPSS 16.0 (SPSS Inc., Chicago, IL). One-way ANOVA and Kruskal-Wallis ANOVA on Ranks were used to compare differences among the three outcome groups. Pair wise multiple comparisons were done with Tukey's or Dunn's tests. We used the t-test or Mann-Whitney U-test to determine differences between two groups. The McNemar test was used to compare related dichotomous variables. Statistical significance was defined at a $p < 0.05$.

RESULTS

One hundred and thirty-eight comatose survivors after a cardiac arrest were admitted to Stanford University Medical Center over the past four years and 83 (60%) were enrolled in the study. Screen failures included: consent could not be obtained ($N=10$), severe coexisting systemic disease or a $mRS \geq 3$ prior to the arrest ($N=21$), pre-existing "do not resuscitate" status ($N=4$), brain death ($N=5$), patient died on day 1 prior to enrollment in the study ($N=7$), inability to undergo MRI due to metallic object in the body ($N=6$), and patient was admitted to our hospital beyond the 1-week study window ($N=2$).

Of the 83 prospectively enrolled patients 71 (86%) underwent 91 brain MRIs. Fifty-six patients had one MRI, 10 patients two MRIs, and five patients three MRIs. Reasons why a brain MRI could not be obtained in 12 patients were: prompt pacemaker placement ($N=2$), cardiac death ($N=1$), removal of life support prior to the MRI being obtained ($N=8$), and withdrawal of study consent ($N=1$). No adverse events occurred during transport to or from the MRI scanner or during MRI acquisition.

Of the 71 patients with MRIs, 20 were excluded from this analysis for medical and MRI technical reasons. Five patients were excluded because their cardiac arrest was secondary to drowning ($N=3$), hanging ($N=1$), or exsanguination ($N=1$) rather than a (presumed) primary cardio-respiratory event. Seven patients were excluded because their first MRI was performed more than one week after the arrest. In four of these patients MR imaging was delayed because of delays in MRI scheduling and in three because the patient was deemed medically too unstable to undergo MRI during the first week. Lastly, the MRIs of eight patients were technically inadequate for quantitative DWI analyses and could not be included in the analyses.

Thus, 51 patients with 62 brain MRIs obtained within 7 days after the arrest are included in this report. Baseline characteristics are shown in table 1. Of these 51, 29 patients underwent SSEPs at a median of 72 hours (IQR 68–96) after the arrest and 47 had a routine EEG recording at a median of 72 hours (IQR 59–100) after the arrest. Forty patients met the prespecified criteria used to determine ADC thresholds associated with prognosis: 21 patients were in group 1 (poor outcome), 13 in group 2A (good outcome), and six in group 2B (survival with impaired functional outcome). Eleven patients died without meeting specific prognostic criteria for poor outcome either because of a second cardiac arrest ($N=1$) or because they were taken off life support ($N=10$) at a median of 5.5 days (IQR 4.0 – 9.5) after their arrest. These patients were not included in the ADC threshold analyses because their long-term prognosis had they not been taken off life support was considered uncertain. Most patients in group 2B lived at home but remained dependent on others for daily support due to cognitive disability. Arrest duration was longer in the group 1 patients than in survivors (groups 2A and 2B combined) ($p=0.004$).

Inter-rater agreement of the MRI measurements was excellent (Intraclass Correlation Coefficient = 0.998). The percentage of brain volume with an ADC value below $650\text{--}700 \times 10^{-6} \text{ mm}^2/\text{sec}$ best differentiated between group 1 and survivors (groups 2A and 2B combined) ($p < 0.001$), while the $400\text{--}450 \times 10^{-6} \text{ mm}^2/\text{sec}$ threshold best differentiated between survival with an independent lifestyle (group 2A) and survival with impaired functional outcome (group 2B) ($p = 0.003$) (Figure 1). The 650 and 700 ADC thresholds were both equally effective in differentiating between group 1 and survivors. Similarly the 400 and 450 ADC thresholds both performed equally in differentiating between groups 2A and 2B. Mean brain ADC values did not differentiate as well between outcome groups as did the percentage of brain volume below these ADC thresholds. The control group consisted of eight women and seven men with a mean age of 46 ± 13 years. Mean brain ADC in the control group was $815 \pm 21 \times 10^{-6} \text{ mm}^2/\text{sec}$.

Representative Case Studies

Case 1—A 22 year-old graduate student with Kawasaki disease in childhood suffered a cardiac arrest while jogging. Cardiopulmonary resuscitation (CPR) was started immediately and spontaneous circulation was restored after 14 minutes. On admission his brainstem reflexes were intact, but he was extensor posturing. Induced hypothermia was initiated for 24 hours. A brain MRI obtained 64 hours after the arrest showed subtle areas of reduced diffusion in the cerebellum and the thalami bilaterally (Figure 2A). He regained consciousness 3 days after the event initially with disorientation and short term memory loss. On neuropsychological testing at 6 months he scored below expected levels in the areas of attention/working memory, verbal/academic skills, and verbal/visual episodic memory. Despite this, he reported no cognitive deficits and graduated two years later.

Case 2—A 37 year-old woman with Churg-Strauss disease and a cardiomyopathy suffered a cardiac arrest. Spontaneous circulation was restored after 25 minutes and on admission she was in a deeply comatose state. After 72 hours her brainstem reflexes were present and she was withdrawing to pain in all extremities, but she had no eye opening. Brain MRI showed areas of restricted diffusion involving the cerebellum, brainstem, thalami, basal ganglia, cortex, and corona radiata bilaterally (Figure 2B). She regained consciousness after 10 days but had severe cognitive deficits with disorientation and short term memory loss. Six months later she was home but dependent on others for daily activities.

Case 3—A 66 year-old man with an ischemic cardiomyopathy collapsed while hiking. He received CPR promptly. A perfusing rhythm was restored after 30 minutes. He underwent induced hypothermia for 24 hours. On day 3 he had intact brainstem reflexes, but he was extensor posturing and had undetectable cortical responses bilaterally by SSEPs. Brain DWI at 67 hours showed widespread areas of severely reduced diffusion in the cortex, subcortical white matter, internal capsule, thalamus, basal ganglia, brainstem, and cerebellum bilaterally (Figure 2C). He never regained consciousness and five days after the arrest he died from a recurrent myocardial infarction.

The effect of timing of the MRI and ADC values during the first week

Case study—A 51 year-old woman suffered a cardiac arrest while in our hospital. Cardiopulmonary resuscitation was initiated immediately and spontaneous circulation was restored after 19 minutes. She remained deeply comatose. A brain MRI obtained two hours after the event showed only limited evidence of global ischemic brain injury (Figure 3A). However, a repeat MRI 53 hours later, showed very severe widespread areas of restricted diffusion involving the cortex of both hemispheres (Figure 3B).

To further assess the effect of timing of the MRI on change in brain ADC values during the first seven days we determined the moving average of the percentage brain volume with an ADC value $<650 \times 10^{-6} \text{ mm}^2/\text{sec}$ in survivors versus patients who died or remained vegetative including all 51 patients with 62 MRIs (Figure 4). The figure shows that quantitative DWI appears to best differentiate patients who die (or remain vegetative) from survivors between 49 and 108 hours after the arrest.

Individual outcome prediction

Thirty-two patients in our dataset had an MRI between 49 and 108 hours after the arrest. Table 2 compares the performance of the neurological exam at 72 hours with quantitative DWI in these patients in this time window. The neurologic exam was considered 100% predictive of death (or vegetative state) if the patient had no motor response or absent pupillary reflexes at 72 hours in the absence of sedating medications. Based on a 10% cut-off value of brain volume below $650 \times 10^{-6} \text{ mm}^2/\text{sec}$, quantitative DWI identified 81% of these patients with 100% specificity. In contrast, the neurological exam resulted in a sensitivity of only 43% (with 100% specificity) in the same patients. All but one of the patients who were classified correctly by the neurological examination were also classified correctly by MRI, whereas MRI correctly classified an additional nine (43%) patients who were classified incorrectly by the examination ($p=0.021$). Thus quantitative DWI at this threshold resulted in a 38% absolute increase in sensitivity for predicting poor outcome as compared to the neurological examination while maintaining 100% specificity ($p=0.021$).

Nineteen patients in this study underwent both SSEPs at 72 hours and a brain MRI between 49 – 108 hours after the arrest. Of these, 14 patients died and one remained in a vegetative state at 6 months. The SSEP was considered 100% predictive of poor outcome if cortical evoked responses were unrecordable bilaterally. Both MRI and SSEP predicted poor outcome with 100% specificity. However, there was a trend towards greater sensitivity for poor outcome of DWI ($12/15 = 80\%$) than SSEP ($9/15 = 60\%$) ($p=0.25$) in this subset of patients.

DISCUSSION

While DWI has been shown to be of unprecedented value in the management of acute ischemic stroke, there is only limited data on its utility in adult patients with global ischemic brain insults^{8,9,11–16}. Since it is challenging to clinically quantify the severity of global hypoxic ischemic brain injury by MRI, we elected to analyze the relationship of patient outcome with quantitative ADC values. Our preliminary results, derived from a prospective series of 51 patients, indicate that quantitative brain DWI may be a useful adjunct in the prediction of neurological outcome for comatose post-cardiac arrest patients. It may not only identify those who die or cannot regain consciousness, but it may also provide information on the likelihood of long-term neurological impairment among survivors.

Of the 83 patients enrolled prospectively, 71 (86%) were able to undergo MR imaging and only three patients (4.2%) could not be scanned within seven days because of medical instability. A total of 91 scans were obtained in 71 patients and no safety concerns or events were noted during MRI acquisition or during transport to and from the MRI suite. Thus, in our experience, MR imaging is feasible and safe in comatose post-cardiac arrest patients. With continued advances in MRI scan times and access, we anticipate that an even higher proportion of post-cardiac arrest patients will be able to undergo MR imaging in the future.

The percentage of brain volume below an ADC cut-off of $650 \times 10^{-6} \text{ mm}^2/\text{sec}$ best differentiated between survivors and patients who died or remained vegetative. The percentage of brain volume below $450 \times 10^{-6} \text{ mm}^2/\text{sec}$ best distinguished between survivors

with good (GOS 4 or 5) versus impaired neurological outcome (GOS 3) at 6 months. The cut-offs identified in this study need to be prospectively validated in an independent data set with a larger sample size. With more data it may become evident that different cut points better predict poor outcome (death or vegetative) or better differentiate between survivors with and without cognitive disability.

The sooner patients who cannot regain consciousness can be identified by MRI, the more useful it will be as a prognostic adjunct. Our results suggest that DWI within hours after cardiac arrest may not show the extent of the ischemic brain injury and that ADC changes continue to evolve over hours to days. Several published human case reports confirm this finding^{17,18}. DWI studies in animal models have demonstrated a decline in brain ADC values during arrest, which reverses during resuscitation^{19–21}. Despite successful reperfusion, however, secondary energy failure and ADC decrease often occur after several hours²². Our observations support the notion that DWI changes induced by global hypoxic cerebral injury in humans evolve slowly and peak around 2 to 4.5 days after the arrest. Therefore, the prognostic accuracy of brain ADC values is expected to be time dependent. To further assess the temporal profile of brain DWI in post-cardiac arrest patients, serial imaging in a larger group of patients is planned.

As comatose post-cardiac arrest patients now often undergo induced hypothermia for 24 hours followed by passive rewarming over at least 8 hours, the clinically relevant time window for prognostic data collection typically starts around 36 hours. All brain MRIs in this study were obtained after return to normal body temperature in patients undergoing induced hypothermia as brain temperature may affect ADC values. Thus the results of this study may not apply to patients undergoing brain DWI at lower body temperatures.

Guidelines for prediction of outcome in comatose survivors after cardiopulmonary resuscitation are almost exclusively based on data derived from patients who did not undergo therapeutic hypothermia. It is of interest that within the context of our study, in which 61% of patients underwent hypothermia, we did not observe any false predictions of poor outcome based on the clinical examination or SSEPs at 72 hours. However, validation of the currently accepted prognosticators in a large cohort of patients undergoing therapeutic hypothermia is needed.

We do not anticipate that DWI will be used in isolation as a prognosticator for post-cardiac arrest patients, but rather in conjunction with other prognostic variables. Our results suggest that quantitative DWI may not only increase the sensitivity of poor outcome prediction, but also provide information on the likelihood of long-term cognitive deficits in survivors. In addition, a relatively normal brain MRI may encourage physicians and families to provide continued life support in patients who are perceived to have a poor outcome in the absence of meeting specific conventional prognosticators for poor outcome, and hence save lives. Eventually, a quantitative prognostic outcome model incorporating quantitative DWI with variables such as levels of serum markers, serial neurological assessments and results of physiological tests is likely to prove most powerful in assisting in decision making regarding continuation or withdrawal of life support in these patients.

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Figure 1.

Panel A: Percentage of brain volume with an ADC value below $650 \times 10^{-6} \text{ mm}^2/\text{sec}$ for group 1 (poor outcome) patients and survivors (groups 2A and 2B combined). Median 19.7% (interquartile range 14.8–45.9) and 4.8% (interquartile range 3.6–6.9), respectively ($p < 0.001$).

Panel B: Percentage of brain volume with an ADC value below $450 \times 10^{-6} \text{ mm}^2/\text{sec}$ of group 2A (survival with good outcome) and group 2B (survival with impaired functional outcome). Median 0.19% (interquartile range 0.12–0.24) and 0.70% (interquartile range 0.31–1.19), respectively ($p = 0.003$).

Figure 2.

Panel A: Brain DWI and corresponding color ADC map 64 hours after his cardiac arrest in a 22 year-old male. He awoke 3 days after the event and had a good neurological recovery at 6 months. Subtle areas of restricted diffusion are seen in the thalami and cerebellum bilaterally. Two percent of brain volume had an ADC value below $650 \times 10^{-6} \text{ mm}^2/\text{sec}$ and 0.12% below $450 \times 10^{-6} \text{ mm}^2/\text{sec}$. The color ADC map shows pixels with an ADC value of 300–400 in red, 400–500 in orange, 500–600 in yellow, 600–700 in light green, 700–800 in dark green, 800–1200 in light blue, and 1200–2000 in dark blue.

Panel B: Brain DWI and corresponding color ADC map in a 37 year-old female with impaired neurological outcome 52 hours after a cardiac arrest. Widespread areas of restricted diffusion are seen in the cerebellum, thalami, basal ganglia, subcortical white matter, and cortex bilaterally. Six percent of brain volume had an ADC value below $650 \times 10^{-6} \text{ mm}^2/\text{sec}$ and 0.29 % below $450 \times 10^{-6} \text{ mm}^2/\text{sec}$.

Panel C: Brain DWI and corresponding color ADC map in 66 year-old Asian male 67 hours after a cardiac arrest. This patient had intact brainstem reflexes at 72 hours, but he was extensor posturing and had undetectable cortical responses bilaterally by somatosensory evoked potentials. Widespread areas of severely restricted diffusion are seen in the cortex, subcortical white matter, internal capsule, thalamus, basal ganglia, brainstem, and

cerebellum bilaterally. Thirty-five percent of brain volume had an ADC value below $650 \times 10^{-6} \text{ mm}^2/\text{sec}$ and 7.7% below $450 \times 10^{-6} \text{ mm}^2/\text{sec}$.

Figure 3.

Panel A: Brain DWI and corresponding color ADC map obtained in a comatose patient two hours after a 19 minute cardiac arrest showing evidence of limited hypoxic-ischemic brain injury.

Panel B: Repeat DWI obtained in the same patient 53 hours later showing widespread areas of restricted diffusion involving the cortex of both hemispheres. See legend of figure 2 for the ADC values on the color ADC map.

Figure 4.

Moving average of the percentage of brain tissue with $\text{ADC} < 650 \times 10^{-6} \text{ mm}^2/\text{sec}$ in comatose post-cardiac arrest patients who died (gray) and survived (white) in the first week after the cardiac arrest (N=51 patients with 62 MRI scans). Note that there is a significant difference between the two groups between 49 and 108 hours after the arrest. s = # of survivors, d = # of patients who died.

Table 1

Characteristics of 51 comatose post-cardiac arrest patients.

Age in years (mean $\pm$ SD)	57 $\pm$ 15
Male gender # (%)	31 (61)
Diabetes Mellitus # (%)	8 (16)
Hypertension # (%)	20 (39)
Coronary Artery Disease # (%)	10 (20)
Arrest duration in minutes (mean $\pm$ SD)	24 $\pm$ 15 [†]
In-hospital cardiac arrest # (%)	14 (27)
Induced hypothermia # (%)	31 (61)
Surface based cooling # (%)	13 (42)
Catheter based cooling # (%)	16 (52)
Surface and catheter based cooling # (%)	2 (6)
Time to first MRI in hours (mean $\pm$ SD)	88 (44)

[†] unknown in 5 patients

Comparison of the prognostic value of the neurologic examination and quantitative DWI in 32 patients with DWI obtained between 49 and 108 hours after the arrest.

Table 2

	# poor outcome	FP*	FN*	TP*	TN*	SEN*	SPEC*	PPV*	NPV*
exam	21	0	12	9	11	43%	100%	100%	48%
MRI	21	0	4	17	11	81%	100%	100%	73%

* FP= # of patients with a false positive test result, FN= # of patients with a false negative test result, TP= # of patients with a true positive test result, TN = # of patients with a true negative test result, SENS= sensitivity, SPEC= specificity, PPV= positive predictive value, NPV= negative predictive value.