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Research Article

Efficacy of Extracorporeal Membrane Oxygenation in Severe Aluminium Phosphide Poisoning Cases: A Real World Experience

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ABSTRACT

Purpose: Aluminium phosphide poisoning is common among agriculture dominant economies especially southeast Asia. Mitochondrial toxicity caused by AlP leads to hemodynamic collapse without any antidote. Mortality is high despite optimum supportive care. In anecdotal studies Extra-Corporeal Membrane Oxygenation (ECMO) has been shown to reduce mortality.

Methods: This was a retrospective single centre study of aluminium phosphide cases managed from 2019 to 2023. Data of all cases who underwent treatment with ECMO was retrieved and analyzed.

Results: Of 182 cases admitted with diagnosis of AlP poisoning 78 underwent VA (Veno-Arterial) ECMO (mean age 34.4years). 60 (76.9%) had multi-organ dysfunction at the time of presentation. 74 (94.9%) of the subjects had ECG changes. ECMO was initiated in emergency room in 68 (87.2%) whereas in 8 (10.3%) ECMO was initiate during CPR. Most subjects required concurrent renal replacement therapy initiation (53, 67.9%). Mean time to ECMO initiation was 1.48 ± 1.2 hours from arrival to ER. Mean duration of ECMO was 50.1 ± 23.9 hours and mean ICU length of stay was 7.17 ± 5.6 days. Out of 78 cases, 53 survived and 25 expired despite ECMO support. During the hospital stay, 15 (19.2%) developed one or the other ECMO related complications lactate levels at the time of arrival were significantly higher among the patients who died (p=0.026).

Conclusion: VA-ECMO was found to be associated with significant survival benefit in high risk cases of AlP poisoning. Close monitoring of the blood gas parameters and cardiac function variables is vital for identifying the potentially salvageable cases.

Keywords: Aluminium phosphide; ECMO; Poisoning; Celphos

INTRODUCTION

Aluminum Phosphide (AlP) tablets, also known as celphos/rice tablets/wheat pills, are commonly used as rodenticide and insecticide for stored grains, especially in southeast Asia. AlP has high market demand reaching approximately 4.3 metric tons in 2023, globally. India and China with large agricultural sectors are major consumers of AlP. Due to its high toxicity and fatality,

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it is banned/regulated in many countries. In India, AlP is an easily available and relatively cheap rodenticide. Due to easy and unregulated access, it has become a tool of self-harm in cases of suicidal attempts [1].

When AlP comes in contact with moisture, it releases a highly toxic gas-phosphine. This gas acts on cytochrome c oxidase and generates free radicals which eventually causes cellular and mitochondrial damage. Inhibition of mitochondrial electron transport chain impairs ATP production. This leads to energy crisis in cardiomyocytes decreasing their contractility and function. Phosphine also alters membrane permeability to sodium, calcium and magnesium leading to electrolyte imbalances. Phosphine induces necrosis and apoptosis of cardiomyocytes which lead to focal myocardial necrosis. The combined effect of these alterations leads to myocardial depression, decreased cardiac output, bradycardia and hypotension. The resultant cardiogenic shock is often refractory to conventional therapies. Diagnosis is usually established with clinical history, and garlic odor in the breath at presentation. Diagnosis can be confirmed with silver nitrate test on gastric aspirate which confirms the presence of phosphine. Till date, there is no antidote available for AlP. Among patients presenting with florid symptoms the mortality, despite conventional and aggressive resuscitative management, has been nearly 100% [2].

Several pharmacological interventions have been tried in the management of AlP poisoning like high dose insulin therapy, N-acetylcysteine and lipid emulsion therapy. However, none of them have been able to demonstrate improvement in survival rates in prospective clinical trials, and supportive care remains the cornerstone of treatment.

Advanced cardiovascular and respiratory support by Extracorporeal Membrane Oxygenation (ECMO) is seen as a valuable modality in severe AlP poisoning. Few small studies have documented successful outcomes using ECMO in AlP poisoning. In this study we analyzed and have presented our experience of AlP poisoning subjects treated with ECMO. To the best of our knowledge this is the largest data for use of ECMO in AlP poisoning cases [3].

MATERIALS AND METHODS

We conducted a single center retrospective study at a tertiary care center in northern India. Case records of the patients with alleged history of AlP poisoning who got admitted to the hospital from August 2019 to July 2023 were retrieved. Among those subjects who were treated with ECMO were selected for data analysis. Permission for waiver of consent was obtained from Institutional Ethics Committee (KSSH/IEC/AL/02). Subjects with incomplete data, those who did not have a confirmed history of AlP ingestion, those who were unwilling for treatment and those who left the hospital against medical advice were excluded from analysis. The data collected included-demographic profile, clinical presentation, vitals at presentation, blood gas parameters (arterial blood gas-ABG) and 2D echocardiography findings, details of VA (Veno-Arterial) ECMO, ECMO related complications, ICU length of stay and hospital mortality [4].

Primary objective of the study was to analyze the role of VA ECMO therapy on survival outcomes of patients suffering from high-risk AlP poisoning. Secondary objectives included frequencies and severity of ECMO related complications, ICU length of stay, need of renal replacement therapy and identifying factors influencing success of ECMO.

The study hospital is a high-volume center for ECMO with over 30 cases treated with ECMO annually. There are no risk stratification criteria described in literature for AlP poisoning cases. Institutional protocol for categorized AlP poisoning patients into low-risk and high-risk. The high-risk criteria are based on presence of any one of the following variables: Arterial pH ≤ 7.1; lactate ≥ 10 mmol/l; systolic blood pressure ≤ 90 mmHg, despite volume resuscitation and inotropic support; Left Ventricular Ejection Fraction (LVEF) ≤ 30% [5].

All high-risk patients were offered VA ECMO support with or without renal replacement therapy (Continuous Renal Replacement Therapy (CRRT) or Slow Low Efficiency Dialysis (SLED)) support. All low-risk subjects were managed conservatively with close monitoring of above variables. VA ECMO was offered in cases deterioration was observed among low-risk subjects. All cases received the standard of care (as per institutional protocol) which included intravenous intralipid, coconut oil through nasogastric tube, gastric lavage with charcoal tablets, intra-venous soda bicarbonate infusion according to arterial pH and urine output as well as other supportive therapy for ICU.

Employed VA ECMO procedure has been described in full detail previously. In brief, VA ECMO was initiated in operation room or emergency room. Percutaneous venous cannulation was done in either femoral vein or right internal jugular vein. For arterial cannulation (return cannula), common femoral artery was used and tip of cannula was placed near common iliac artery of lower aorta. In order to maintain distal perfusion in lower limb a cannula was inserted antegrade into the common femoral artery with tip directed towards superficial femoral artery. The patients were maintained on a continuous heparin infusion to achieve and maintain an Activated Clotting Time (ACT) between 160 and 200 seconds. Packed red blood cells were transfused during ECMO if hemoglobin level fell below 10 g/dL and single donor platelets were transfused if the platelet count were less than 75,000/dL. The patients were monitored for hemodynamic improvement, reversal of metabolic acidosis, and adequate oxygenation. Upon stabilization of hemodynamic and other clinical parameters, the ECMO weaning protocols were initiated. The circuit flow was gradually reduced to assess the native cardiac function in the background of increased venous return. Decannulation was performed once the patient had improvement in LVEF (above 40%), maintaining systolic blood pressure of more than 90 mmHg without any inotropic support and acidosis had completely recovered [6].

The data was compiled into an excel sheet and coded and curated for further analysis. Quantitative demographic data was normally distributed as tested using Kolmogorov-Smirnov test. Later data was transferred into IBM® SPSS® (Statistical Package for Social Sciences) version-29 for statistical analysis. The relationship between the two categorical variables was

analyzed using the *Chi-square* test, and comparison between categorical and continuous variables was done using independent student t-test. All clinically relevant, biologically plausible and exploratory relationships between different variables were tested using appropriate tests and groupings were done accordingly. One sample, non-comparative Kaplan Meier survival curve was also drawn for survival and length of hospital stay. STROBE guidelines by EQUATOR network were adhered to while writing of the manuscript [7].

RESULTS

Over 4 years period, 182 cases were admitted with primary diagnosis of AlP poisoning of which 78 underwent ECMO. Cases with incomplete dataset, stable enough for observation and those who were discharged against medical advice were excluded from analysis (Figure 1). Among them, majority were males and from rural background with mean age 34.41 ± 11.7 years. Most common reason of poisoning was suicidal ideation. Almost all subjects were referred from one or more hospital before reaching the ECMO center (Table 1). Majority cases (69, 88.5%) were upfront with the history of AlP consumption but only 2 were able to ascertain the exact amount of consumption. Most cases presented during the months of August-October.

Table 1: Demographic and patient's characteristic.

Variables		ECMO cases (N=78)
Age (yrs)		34.4 (11.7)
Sex	Male	61 (78.2%)
	Female	17 (21.8%)
Residence	Rural	57 (73.1%)
	Urban	21 (26.9%)
Time to arrival (hr)		3.3 (1.9)
ECMO initiation	Elective	68 (87.2%)
	ECPR	08 (10.3%)
	Mobile	02 (2.6%)
ECG changes		74 (94.9%)
Multi-organ dysfunction		60 (76.9%)
Inotrope requirement		78 (100%)
pH on arrival		7.14 (0.16)
Lactate on arrival (mmol/L)		12.7 (4.9)
LVEF on arrival (%)		21.79 (6.0)
Worst pH		6.9 (0.8)
Worst lactate (mmol/L)		20.1 (5.2)
Worst LVEF (%)		19.0 (4.1)
Mortality		25 (32.1%)
ECMO complications		63 (80.8%)
ICU-LOS (days)		7.17 (5.6)
Hospital-LOS (days)		9.01 (6.5)

Time to arrival (hr)	3.3 (1.9)
Multiorgan dysfunction	60 (76.9%)
Renal replacement therapy	53 (67.9%)

Note: Data presented as n (%), mean (SD). LVEF: Left Ventricular Ejection Fraction; ECMO: Extracorporeal Membrane Oxygenation; ICU-LOS: Intensive Care Unit Length of Stay, Hospital-LOS: Hospital Length of Stay; ECG: Electrocardiogram

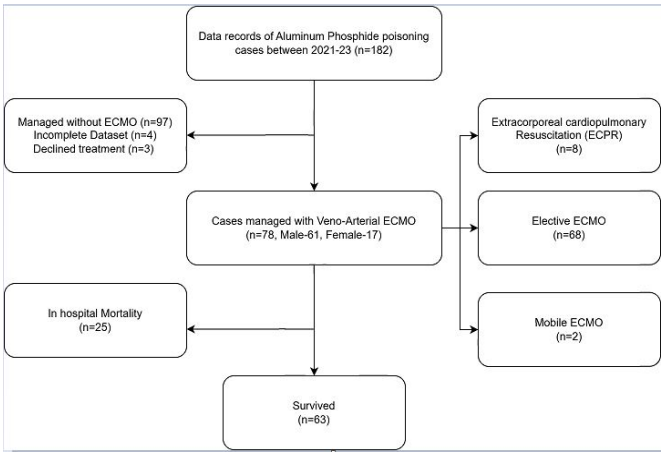


Figure 1: Flow diagram of the study cohort (ECMO: Extracorporeal Membrane Oxygenation).

At the time of presentation, all subjects were in hypotension and required inotropic support. 36 (46.2%) subjects were in altered sensorium and 60 (76.9%) had multi-organ dysfunction at the time of presentation. 74 (94.9%) of the subjects had ECG changes, most common being broad complex tachycardia on arrival. ECMO was eventually initiated in 68 (87.2%) whereas in 8 (10.3%) subjects ECMO was initiate during CPR and among remaining two subject mobile ECMO was employed. During hospital stay most subjects required concurrent renal replacement therapy initiation (53, 67.9%). There was a mean delay of 3.57 ± 1.9 hours from the time of consumption to arrival to ER [8].

All patients had poor hemodynamics and arterial blood gas parameters at the time of presentation (Table 2). Mean time to ECMO initiation was 1.48 ± 1.2 hours from arrival to ER. Mean duration of ECMO was 50.1 ± 23.9 hours and mean ICU length of stay was 7.17 ± 5.6 days. Out of 78 cases, 53 (67.9%) survived and 25 expired despite ECMO support. During the hospital stay, 15 (19.2%) developed one or the other ECMO related complications like sepsis, limb ischemia, hemolysis, gastrointestinal bleed and limb disarticulation [9].

Table 2: Patient's characteristic with differences between survivors and non-survivors.

Variables		ECMO cases (N=78)	Survivors (N=53)	Non-survivors (N=25)	P value
Age (yrs)		34.4 (11.7)	34.7 (11.2)	33.8 (12.8)	0.419
Sex	Male	61	43	18	0.831
	Female	17	10	7	
ECG changes		74	49	25	0.158
Multi-organ dysfunction		60	36	24	0.006
Time to arrival (hr)		3.3 (1.9)	3.4 (1.9)	3.0 (2.0)	0.463
Time to initiate ECMO (hr)		1.5 (1.8)	1.73 (2.0)	0.96 (0.7)	0.057
ECMO initiation	Elective	68	47	21	0.338
	ECPR	8	4	4	
	Mobile	2	2	0	
pH on arrival		7.14 (0.16)	7.15 (0.15)	7.12 (0.17)	0.411
LVEF on arrival (%)		21.79 (6.0)	22.6 (5.9)	20.0 (6.0)	0.896

Lactate on arrival (mmol/L)	12.7 (4.9)	12.4 (4.3)	13.2 (6.0)	0.026
Worst pH	6.9 (0.8)	6.9 (0.9)	6.9 (0.1)	0.33
Worst lactate (mmol/L)	20.1 (5.2)	19.0 (4.7)	22.5 (5.4)	0.238
Worst LVEF (%)	19.0 (4.1)	19.5 (3.9)	17.8 (4.1)	0.484
Duration on ECMO (hr)	50.0 (23.9)	50.4 (16.8)	49.2 (34.8)	<0.001
ICU-LOS (days)	7.17 (5.6)	8.3 (5.2)	4.9 (5.8)	0.317
Hospital-LOS (days)	9.01 (6.5)	11.0 (5.9)	4.9 (5.8)	0.856
Renal replacement therapy	53	32	21	0.037
ECMO related complications	63	44	19	0.463

Note: Data presented as n (%), mean (SD). LVEF: Left Ventricular Ejection Fraction; ECMO: Extracorporeal Membrane Oxygenation; ICU-LOS: Intensive Care Unit Length of Stay; Hospital-LOS: Hospital Length of Stay; ECG: Electrocardiogram

In order to identify the factors influencing survival rates, we performed *Chi-square* test among all categorical variables. Presence of multiorgan dysfunction was associated with poorer survival rates (p=0.006), similarly requirement of renal replacement therapy was associated with higher risk of death compared to no requirement (p=0.037). Nature of ECMO initiation (emergent or ECPR or Mobile) and development of ECMO related complications had no bearing on the outcomes. Subsequently we performed independent t test to identify risk factors for mortality among AlP cases who were being managed on ECMO. Oddly, time to initiation of ECMO was significantly higher in the survivor group (2.0 ± 1.7 hours) as compared to the mortality group (0.96 ± 0.7 hours) (t(-1.82), p=0.047). Duration on ECMO was also significantly higher in the survivor group (50.4 ± 16.8 versus 48.2 ± 34.8 hours, t(-0.192), p<0.001). Lactate levels at the time of arrival were significantly higher among the patients who died (13.2 ± 6.0 mmol/L) compared to the group that survived (12.4 ± 4.3 mmol/L, t(0.67), p=0.026). None of the other variables including LV ejection fraction, arterial pH, length of ICU or time from consumption to hospital arrival had any impact on the survival outcomes.

It was also revealed in the independent t-test analysis that time to ECMO initiation was significantly higher in the group which did not face any ECMO related complications (1.0 ± 0.5 versus 1.9 ± 1.6 hours; t(-1.18), p=0.036). ICU length of stay was significantly higher in the group developing ECMO related complications as compared to the group without any complications (12.1 ± 8.9 versus 6.0 ± 3.6 days; t(4.26); p<0.001). Follow up analysis for identifying the factors linked to the requirement of renal replacement therapy, independent t test analysis revealed that length of ICU stay was significantly shorter in the cases where RRT was not required (5.4 ± 2.2 versus 8.0 ± 6.4 days; t(-2.0); p=0.002). Additionally, low arterial pH was associated with higher risk of use of RRT both in term of worst pH value (p=0.013) as well as pH value at the time of arrival (p=0.04). However, lactate levels, LV ejection fraction and time to hospital arrival or time to ECMO initiation were similar between the group requiring RRT versus those who did not require RRT.

Additional *Chi-square* analysis showed that the frequency of ECMO related complications was statistically less frequently encountered in cases where RRT was initiated (p=0.02) but there was no difference between frequency of ECMO related complications versus frequency of development of multi-organ dysfunction (p=0.09). Kaplan Meier survival curves were developed for identifying the survival temporal characteristics of subjects who died during treatment (Figure 2). Other variables like vitals at the time of arrival or age or sex did not influence the development of ECMO related complications or multi-organ dysfunction.

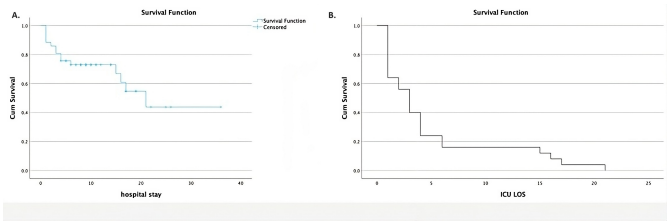


Figure 2: Kaplan-Meier curve to analyse survival characteristics of the study cohort based on A) Hospital stay and B) ICU length of stay.

DISCUSSION

In this retrospective study we have reported the real-world data of the use of ECMO in high-risk cases of AlP poisoning. As per PubMed search till 30th November 2024, this is the largest data set on the subject. The intervention of ECMO led to survival of 67.9% subjects of high-risk category. Despite expected complications, ECMO was found to be safe, feasible and effective in patients with significant hemodynamic compromise of near-fatal AlP poisoning.

The economy of developing countries like India are predominantly driven by agriculture with over 60% population

living in rural areas and dependent of farming activates. Insecticides, weedicides and rodenticides are commonly used in these areas. Apart from agricultural use, AlP is commonly used to fumigate stored grains. AlP was second most common used agriculture poison as per a retrospective study by National Poisons Information Centre of India. The reported fatal dose of AlP as per literature is as little as 0.15-0.5 gm. As reported in previously literature we also found its use more commonly in younger, rural and male predominant population with most cases having suicidal ideation history. The systematic review of more than 350 studies have shown no effective antidote or evidence-based protocol for managing acute AlP poisoning. Though there are anecdotal case reports of clinical benefit of agents like N-actyl Cysteine (NAC), glucose-insulin-potassium infusion, vitamin E, gut decontamination using oils and fresh packed RBCs infusion in management of AlP poisoning with some mortality benefit. A meta-analysis studying the role of four antioxidants: NAC, L-Carnitine, Vitamin E, and Co-enzyme Q10 on outcome of AlP poisoning found that antioxidant decreased mortality, need of intubation and mechanical ventilation with significant heterogeneity and high reporting bias in the data. The use of blood purification techniques such as CRRT and SLED has been reported to improve survival rates. Renal replacement therapy is essential for the rapid correction of metabolic disturbances, with high-dose dialysis in CRRT particularly necessary for acute poisoning cases. However, many patients succumb to refractory hypotension or sudden cardiac arrest during the preparation or initiation of CRRT.

There are two modes of ECMO: Veno-Arterial (VA) and Veno-Venous (VV). VV ECMO is preferred modality in respiratory failure without hemodynamic compromise, whereas VA ECMO is preferred in circulatory shock refractory to inotropes. VA ECMO has been used as a salvage therapy in AlP poisoning as the effect of phosphine on cardiac myositis is reversible with no residual sequelae, though the supporting evidence is literature is limited likely due to poor reporting and lack of uniform recommendations. There are two studies (both from same centre) which have reported their experience of using ECMO in AlP poisoning. Criteria used for initiation of ECMO in our study was similar to that reported in previously. The demographic characteristics and presentation were also similar. The overall in hospital mortality in ECMO treated cases was reported to be 32% which was comparable to our study.

Similar to our study, previous articles have also reported ECG changes in 40-80% of cases, with more changes in those managed with ECMO. Tachyarrhythmias were more commonly reported than bradyarrhythmias. Some of our cases (19.2%) had one or other ECMO related complication. The usage of extra-corporeal circuit and anticoagulation, can increase the risk of bleeding, stroke or limb ischemia. Hemodynamic instability during ECMO can cause renal injury and need of renal replacement therapy. Other complications may arise due to canulation procedure and systemic inflammation caused by interaction of blood with ECMO circuit. The studied cases had sepsis, limb ischemia, hemolysis, gastro-intestinal bleed and limb disarticulation as complication of VA ECMO. The most common complication of ECMO (including veno-venous) in poisoning cases as per a review is bleeding at cannulation site (10-36%), however we did not find any significant complications related to bleeding in our patients. The previous study of VA ECMO in AlP poisoning has mainly reported hematoma, surgical correction of vascular access, thrombocytopenia and renal failure as complication.

Lower pH at presentation and lowest recorded pH were related to increase need of RRT. Multi-organ dysfunction and need of renal replacement therapy were linked to poorer survival in our study. In previous study the need of RRT with VA ECMO was associated with increased mortality. In previous studies as well multi-organ involvement (as measured by SOFA score) in such cases has been shown to increase the risk of mortality. Serum lactate level which is a marker of tissue perfusion and microcirculation was related to mortality in our study. Higher lactate level was observed in 8 to 16 hours post ingestion in non-survivors in a study.

Interestingly, longer time to ECMO initiation and longer ECMO duration were associated with higher survival rates in our study. There were higher complications reported on early initiation of ECMO therapy, reflecting upon the urgent need of the procedure. Previous data also shows no difference in outcome with time to ECMO initiation but increased mortality with longer duration of ECMO. This can be explained by lower duration of ECMO in cases with early mortality. The time is calculated from the moment of presentation in the emergency room, at which point the case may not yet be eligible for ECMO. The need for ECMO might arise later. Therefore, this calculation may not accurately reflect the true delay, which is the time from meeting the eligibility criteria to the initiation of ECMO. Also it is reflected in the Kaplan Meier analysis that majority of mortality happens in the first few days of ECMO initiation (Figure 2).

The nature of ECMO initiation (emergent/ECPR/mobile) and ECMO related complications had no impact on outcomes in our study. A retrospective study from German emergency medical services has reported significantly higher chance of survival with good neurological outcome with cardiopulmonary resuscitation in poisoning related out of hospital cardiac arrest. The California Poison Control System based on their retrospective data analysis where ECMO treated patient had survival of 81%, have also recommended the use ECMO for treatment of acute poisoning.

ECMO is a costly intervention and it is ethically justified in cases where primary cause is reversible. AlP poisoning is one such condition where data is showing significant mortality benefit with use of ECMO. Despite the pros, our study was not short of limitations. Most importantly, being single centric limits generalizability of the findings. Being retrospective study from a tertiary care high ECMO volume, our data is prone to selection bias. We also did not analyze the data of cases who improved without the use of ECMO, likely due to mild severity of poisoning. Data of long term follow up was also not retrieved which could have helped in understanding the long term complication of use of ECMO in AlP poisoning. Finally the criteria used of risk stratification were indigenous (though not arbitrary) and probable contribution of each individual variable could have been identified for better generalization of ECMO

indications. In conclusion, AlP poisoning is common in agriculture dominant low and middle income countries. VA-ECMO has demonstrated to be associated with significant survival benefit in high risk cases of AlP poisoning. Close monitoring of the arterial blood gas parameters and cardiac function variables is vital for identifying the potentially salvageable cases.

CONCLUSION

Over two third cases of severe aluminium phosphide poisoning were salvaged using VA-ECMO, demonstrating substantial mortality benefit of this therapy in the management of aluminium Phosphide poisoning.

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CONFLICT OF INTEREST AND FINANCIAL DISCLOSURE

None to declare by any authors.

ETHICS AND CONSENT TO PARTICIPATE DECLARATIONS

Waiver of consent obtained from institutional ethics committee (KSSH/IEC/AL/02 Dated: 05.04.2024).

DATA AVAILABILITY STATEMENT

Anonymized individual patient data can be provided upon permission the hospital administration and institutional ethics committee for individual review and non-publication/non-audit purposes.

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AUTHOR APPROVAL STATEMENT

All authors have read and approved the current version of this manuscript.

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