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Review Article

The Importance of Electrolyte Management in Rural Tele-Intensive Care

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Abstract

Our tele-intensivist program has been recognized for uniquely providing supervision of seriously ill hospitalized patients for nearly nine years to one of the most sparsely populated six-state region of the North Central United States. We are currently monitoring 133 patients in thirty-three hospitals. A staff of one intensivist, two critical care nurses, and an information technician see on average 22.1 admissions per day and perform 925 interventions per month. The third most numerous interventions classified as major by the intensivist was that of severe electrolyte disturbances requiring correction. This was considered as major a problem as diagnosing and managing hypotension and respiratory failure which were the top two most common interventions. For those considered intermediate or minor to the care plan of the patient, electrolyte correction was second to communication with families and providers. Discussed in this report will be a review of recent literature suggesting the importance to prognosis and outcomes of critically ill patients of correction of such electrolyte disturbances. We conclude that these high numbers of successful interventions which contributes to a high throughput of patients monitored each day reflects the welcome acceptance of tele-intensive care to rural hospitals.

INTRODUCTION

History and evolution of Avera eCare™

The Avera Health System launched its telemedicine program by offering consultation by televideo connectivity from the main tertiary hospital in the largest city of the multi-state North Central Region of the United States. The major growth spurt in our rural telehealth program came after the initiation of tele-intensive care called *e*ICU Care® in 2004. Since then multiple other tele-health programs have been initiated and then quickly expanded by demand for additional services.

In a previously published report we described the consequences of our *e*ICU [1]. The project initially started with the tertiary hospital serving as the hub providing twenty-four hour video monitoring and remote patient care of three medium-sized rural hospitals. It evolved to include several more hospitals of that size called "rural regional hospitals." Additionally, more remote "critical access" (20 beds or less) hospitals began to request the coverage. Tele-intensivist supervision further expanded to hospitals outside of our own health system and those with different medical record or electronic record systems. Finally, it expanded to patient supervision in multiple states.

Current status of Avera eICU Care™

Avera *e*Care® now has had several years of experience providing multiple additional telehealth services. These programs have each enjoyed the same growth. After tele-consultation and tele-intensive care, the next phase included the birth and then rapid expansion of programs such as our Emergency, eStroke, and ePharmacy. In several of these, the number of sites exceed the number of *e*ICU services. This could be the result of several factors, but one could postulate that perhaps these services have been more useful to rural sites of care. Now even more varied *e*Services have been born such as *e*Long-Term Care and *e*Urgent Care/Prisons, providing care to an amazing assortment of doctors, clinics, hospitals, and other health care facilities. Since theseservices have been launched, they each have been received beyond expectations. As time progresses and needs arise, unique applications of telemedicine supervision are being developed. Many of these are in the pilot stages in our comprehensive program. Our multiple telehealth services are now largely sustained by internal funding. The start-up portions are usually supported, in part, by grants. With this support we have been able to develop a "headquarters" for all of our multiple tele-health services as a unique service line geographically located in one location.

Contribution of Avera eICU Care™ to quality of care outcomes

After implementation of our tele-intesive care program we were able to compare outcomes to that prior to the program [1]. In the rural setting we improved intensive care unit length of stay and had reduced mortality. We reduced days on mechanical ventilation. These improvements carried forth to the entire hospital stay. We demonstrated reduced length of total hospital stay, and reduced total hospital mortality. We have monitored and improved compliance with best practices such as deep vein thrombosis prevention and gastrointestinal tract ulcer prevention. Finally, we surveyed our participating hospitals and estimated the number of cases that remained local to their initial hospital who otherwise would have been transferred to the tertiary care hospital. From that information we identified over a milliondollars of reduced costs for ground and especially air transport.

The importance of electrolyte correction, acid base management and correction of metabolic disorders by tele-intensive care

There are nearly fifty tele-intensive care programs in the United States today. Our program has consistently had the highest number of interventions per month. At the end of an intervention, the intensivist classifies the action as major, intermediate, or minor. The ten most common major interventions over a five-year period from January 1, 2008 until December 31 2012 in descending order included hypotension, respiratory failure evaluation and management, electrolyte abnormality, airway management, acid-base disturbances, hyperglycemia with active titration of insulin therapy, arrhythmia diagnosis and treatment, sepsis evaluation and treatment, acute renal failure management, and shock evaluation and treatment. The complete list of major interventions is shown in Table 1.

Table 1: Complete list of major interventions.

	eICU Interventions	
VISICU	**Avera Health**	**1/1/2008 to 12/31/2012**
Interventions By Class		

Major	**Total**	**Comments**
Other	3806	
Hypotension – evaluation and management	2091	
Respiratory failure – evaluation and management	1666	
Electrolyte abnormality – evaluation and management	1621	
Airway management	1460	
Acid-Base disturbance – evaluation and management	1264	
Hyperglycemia – active titration of insulin therapy	1264	
Arrhythmia – evaluation and management	1068	
Sepsis – evaluation and management	1033	
Hypoxemia – evaluation and management	868	
Acute renal failure – evaluation and management	787	
Shock – evaluation and management	701	
Hypertension – evaluation and management	459	
Delirium, psychosis, severe agitation – evaluation and management	397	
End of life/care limitation discussion	377	
Change in mental status – evaluation and management	362	
Infection – evaluation and management	305	
Hypotension – initiation/titration of pressors/inotropes	219	
Hemorrhage – evaluation and management	188	
Hypovolemia – evaluation and treatment with fluids	180	
Hypercarbia – evaluation and management	167	
Code management/supervision	152	
Seizures – evaluation and management	115	
Sepsis – severe evaluation and management	69	
Procedure – evaluation and supervision	56	
Shock – evaluation and treatment with pressors/inotropes	55	
Operative interventional procedure – evaluation	49	
Intracranial hypertension – evaluation and management	18	
Adrenal insufficiency – evaluation and management	14	
Major Total	**20811**	

The interventions considered by the tele-intensivist as intermediate interventions includecommunication with other health care providers and/or family, electrolyte abnormality diagnosis and management, hyperglycemia evaluation and treatment, best-practice implementation (deep vein thrombosis prophylaxis, beta-blocker therapy, etc.), and diagnostic test evaluation in that order. Electrolyte and glucose surveillance and treatment were second only to communication with health care providers or family. The most common minor interventions included communication with other healthcare providers and/or family, routine modification to the care plan (i.e. medications for pain or fever), clinical assessment leading to ordering of diagnostic tests, agitation and anxiety diagnosis and treatment, and electrolyte abnormality evaluation and management. Table 2 below shows the complete list of intermediate and minor interventions.

Review of recent literature concerning the impact of electrolyte abnormalities on outcomes in critically ill patients

Every year, a smattering of reports document the impact of abnormalities of electrolytes on hospital length of stay, hospital mortality, intensive care unit admission rates and intensive care unit outcomes. A brief review of several years of these reports will now be presented. A recent study involving 151,486 adult patients from 77 intensive care units over a period of ten years demonstrated that many cases of dysnatremia are acquired in the intensive care unit, and that the severity of dysnatremia is associated with poor outcome in a graded fashion [2]. In 2009 Callahan and others [3] reported that the most common electrolyte abnormality seen in general hospital patients in the United States varying from 1-6% in multipleseries is

Table 2: Complete list of intermediate and minor interventions.

eICU Interventions		
VISICU	**Avera Health**	**1/1/2008 to 12/31/2012**
Intermediate	**Total**	**Comments**
Communication with other healthcare providers and/or family	6725	
Electrolyte abnormality – evaluation and management	5982	
Hyperglycemia – evaluation and treatment	5664	
Best-practice therapies (e.g. DVT, beta blocker, etc.)	5279	
Other	5269	
Diagnostic test evaluation	2200	
Arrhythmia – evaluation and management	2031	
Hypotension – evaluation and management	1947	
Respiratory distress – evaluation and management	1859	
Pain – evaluation and management	1375	
Oliguria – evaluation and management	1348	
Hypertension – evaluation and management	954	
Bleeding – evaluation and treatment with blood products	867	
Medication change / dose adjustment	848	
Hypotension – evaluation and treatment with fluids	741	
Infection – evaluation and management	695	
Hypovolemia – evaluation and management	347	
Coagulopathy – evaluation and management	272	
Hypervolemia – evaluation and management	209	
Change in mental status – evaluation and management	132	
Abdominal pain – evaluation and management	59	
Thrombocytopenia – evaluation and management	40	
Bronchospasm – evaluation and treatment	37	
Intermediate Total	**44880**	
Minor	**Total**	**Comments**
Communication with other healthcare providers and/or family	6680	
Routine modifications to care plan (e.g. PRN medications for pain, fever)	3175	
Clinical assessment – ordering diagnostic tests	1235	
Other	1230	
Agitation/anxiety – evaluation and management	1175	
Electrolyte abnormality – evaluation and management	961	
Minor Total	**14456**	

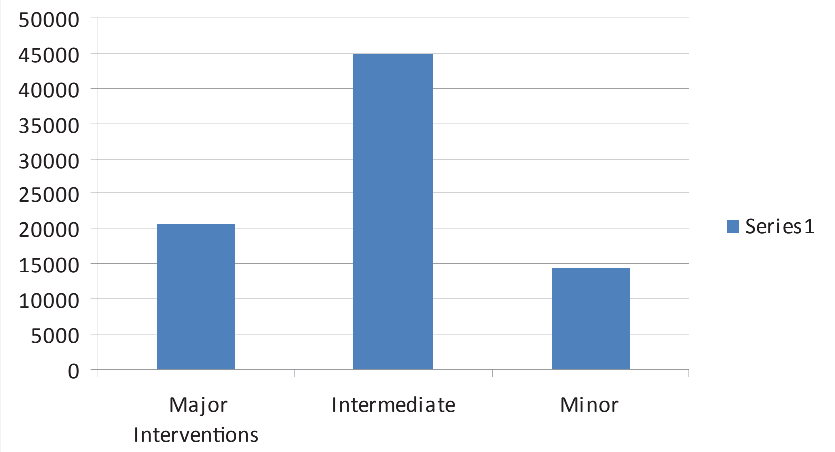

Figure 1 Shows the total number of major, intermediate, and minor interventions.

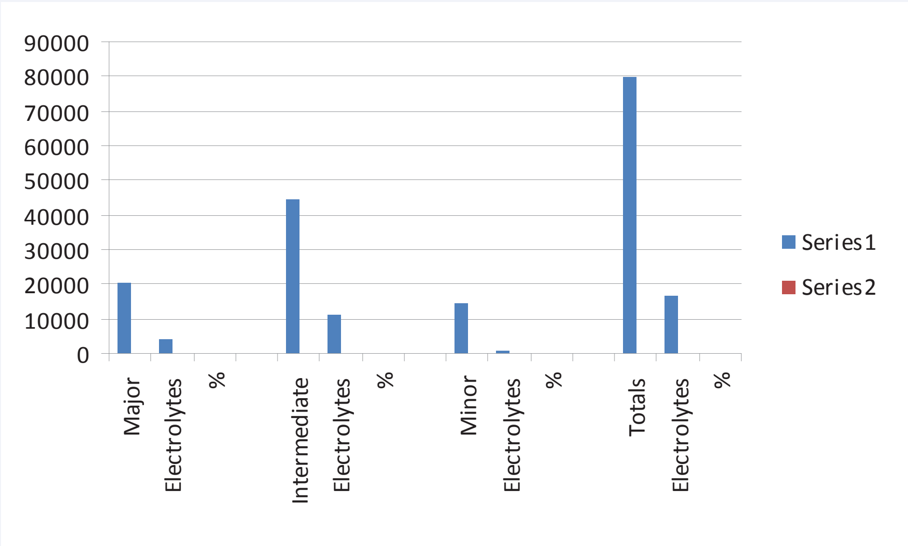

Figure 2 Illustrates the relationship of the electrolyte interventions to the total major, intermediate, and minor interventions.

hyponatremia. Admissions with hyponatremia resulted in an average two days longer length of stay, contributing $3,540 per case. When multiplied times the number of admissions with this electrolyte disorder over a year at a single academic-setting hospital, the total cost of this problem was over a million dollars. Extrapolating to the country at large, they predicted over a billion dollars in additional costs for health care delivery (Figures 1, 2).

In a very recent publication Leung and others reported on the impact of sodium disorders on surgical patients [4]. This was the American College of Surgeons National Quality Improvement Database.In this report, the authors reviewed the 30 day perioperative outcomes in 964,263 adults going to surgery in >200 hospitals from 1/1/2005 to 12/3/2013. They looked at 30 day perioperative outcomes. 75,423 had serum sodium < 135 mEq. They had 44% increased death rate. There was higher 30 day mortality. There were increased perioperative coronary events, wound infections, and pneumonia. Length of stay was increased by 1 full day. Tele-intensive care is suited to the prevention of these disorders of sodium and subsequent poor surgical outcomes.In 2011 Yunosdescribed the importance of reducing chloride rich fluids (normal saline) in consecutive patients admitted to a large multidisciplinary Australian hospital over a six month period of time which prevented hospital-acquired metabolic acidosis and severe acidemia [5]. A tele-intensive care program which provides 24-hour supervision of patients can assist with strategies to ensure use of reduced chloride-rich fluids.

Most clinicians are keenly aware of the impact of major disorders of serum potassium and subsequent outcomes in seriously ill patients. However, a 2012 report [6] suggested that even small deviations of serum potassium from normal had consequences to outcomes after myocardial infarction. In this report the Cerna Health Facts Database was studied. 38,689 patients with acute myocardial infarction in 67 hospitals were reviewed from 1/1/2000 until 12/31/2008. There were two times the mortality in those 4.5 – 5.0 or < 3.5 than those 3.5-4.5

mEq/L. The abnormal values were associated with ventricular fibrillation or cardiac arrest. Tele-intensive care can keep a very close watch on serum potassium to maintain such a narrow normal range.

Disorders of calcium [7] and magnesium [8] have been reported to be quite frequent in intensive care unit patients. Cardiovascular instability, prolonged ventilator support, and higher mortality have been seen in such patients. Low ionized serum calcium is found in 15-20% of critically ill patients and has been associated with increased mortality in the intensive care unit [9,10]. In areport by Attur and associates in 110 patients in a single ICU, serum calcium negatively correlated with APACHE II score and subsequent mortality [11]. In a 2011 report from April to May 2005, patients in Mumbai were reviewed [8]. Those with low serum magnesium had about two extra intensive care unit days. There was longer mechanical ventilation by ~ 2 days. There was twice the mortality despite similar APACHE scores. Serum magnesium is easily monitored and replaced by a telemedicine service. Finally, the prevalence of hypophosphatemia is high in the intensive care unit, about 28% of critically ill patients [12]. Hypophosphatemia is associated with leukocyte, erythrocyte, and platelet dysfunction. In addition, hypophosphatemia has been reported to be responsible for clinical syndromes of muscular weakness, confusion, ataxia, seizures and coma, respiratory failure, cardiacarrhythmias, and cardiomyopathy. We frequently replace serum phosphorus in our telemedicine intensive care program.

Illustrative case report

An 81 year old female with a prior history of diverticulosis and chronic kidney disease presented to a rural hospital with ab-

Table 3: Shows these initial lab abnormalities.

	4/28/13 06:25	4/28/13 06:26	4/28/13 11:35	4/28/13 15:30	4/28/13 15:30
Sodium	135				134
Potassium	4.3				4.3
Chloride	99				100
Carbon Dioxide	26				25
POC Total CO2					
Anion Gap	10				9
BUN	57 H				56 H
Creatinine	2.2 H				2.4 H
GFR Calculation	21				
BUN/Creatinine Radio	25.9 H				23.3 H
Glucose	152 H				143 H
POC Glucose					
Lactic Acid				1.5	
Calcium	10.2				9.0
POC WB Ioniz Calcium					
Phosphorus		6.6 H			
Magnesium		7.4 H	6.5 H		
Iron					
TIBC					
% Saturation					
Unsat Iron Binding					
Ferritin					
Total Bilirubin	0.4				
Direct Bilirubin					
Indirect Bilirubin					
AST	34 H				
ALT	27				
Alkaline Phosphatase	76				
C-Reactive Pro, Quant					
B-Natriuretic Peptide	194 H				
Total Protein	6.1				
	4/28/13 06:25	**4/28/13 06:26**	**4/28/13 11:35**	**4/28/13 15:30**	**4/28/13 15:30**
Sodium	135				134
Potassium	4.3				4.3
Chloride	99				100
Carbon Dioxide	26				25

POC Total CO2					
Anion Gap	10				9
BUN	57 H				56 H
Creatinine	2.2 H				2.4 H
GFR Calculation	21				
BUN/Creatinine Radio	25.9 H				23.3 H
Glucose	152 H				143 H
POC Glucose					
Lactic Acid				1.5	
Calcium	10.2				9.0
POC WB Ioniz Calcium					
Phosphorus		6.6 H			
Magnesium		7.4 H	6.5 H		
Iron					
TIBC					
% Saturation					
Unsat Iron Binding					
Ferritin					
Total Bilirubin	0.4				
Direct Bilirubin					
Indirect Bilirubin					
AST	34 H				
ALT	27				
Alkaline Phosphatase	76				
C-Reactive Pro, Quant					
B-Natriuretic Peptide	194 H				
Total Protein	6.1				

dominal discomfort which had started the night before. She presumed it was related to herchronic constipation. She took capfuls of milk of magnesia which failed to give her relief. At presentation to the hospital she had fever and elevated white blood count and serum magnesium level. Before transfer her exam revealed an irregularly irregular heart rhythm, clear lungs, and a soft abdomen which was non-tender. She had edema. Her lab tests revealed a serum creatinine of 2.2 mg/dL and a serum magnesium level of 7.4 mg/dL. X-ray revealed ileus. Under the direction of our tele-intensive care service, she was given intravenous fluids but the serum magnesium did not decrease (Table 3).

The patient quickly deteriorated and was noted to have mental lethargy, acute worsening of renal function, pulmonary congestion/pneumonia, and worsening ileus. She was treated with broad spectrum antibiotics for possible GI or pulmonary sources of infection. However, it was felt by our tele-intensivist service that the patient was deteriorating in part from thesustained high level of serum magnesium (magnesium toxicity), especially her altered mental status and worsening ileus. A joint decision was made between our tele-intensivist and the primary physician to transfer the patient to our tertiary care facility for initiation of dialysis to further manage hypermagnesemia which was causing or complicating the obstipation, stupor, and subacute diverticulitis.

After transfer to our tertiary care facility dialysis was initiated which surprisingly also failed to definitively lower serum magnesium levels. Dialysis was performed daily for 2-3 hours. Levels were reduced but then boomeranged by the next hospital day. The serum magnesium levels were elevated with each day's morning lab tests, and her obtundation and ileus persisted (Table 4).

Finally, with the use of multiple non-magnesium containing cathartics and enemas, she had multiple large volumes of stools. At first the texture was stony hard, later soft, and still later watery. Her serum magnesium now fell to normal levels (Tables 5, 6, 7).

Once the serum magnesium was consistently reduced, her overall clinical status markedly improved, mental status, pulmonary status (extubated), renal function, and finally the ileus resolved.

The patient was discharged home to finish a course of antibiotics for diverticulitis and pneumonia. She was given instructions to avoid magnesium-containing antacids and cathartics. It was concluded that the GI impaction served as a reservoir for magnesium making the levels rebound even after dialysis. We suggest that this case illustrates the potential impact of hypermagnesemia on critically ill patients, worsening ICU length of stay and time on a ventilator, and requiring hemodialysis for acute symptom control. In addition the case demonstrates the interaction between our tele-intensivist program in assisting the rural practitioner.

SUMMARY AND CONCLUSIONS

In summary, we have described our unique rural telemedicine service line. We presented data on the usual workload of our program which services the North Central region of the United

Table 4: Below demonstrates the recurrently elevated morning magnesium levels despite lowering during daily dialysis.

	4/27/13 12:45	4/27/13 18:30	4/27/13 21:50	4/28/13 01:00	4/28/13 05:48
Sodium					
Potassium					
Chloride					
Carbon Dioxide					
POC Total CO2					
Anion Gap					
BUN					
Creatinine					
GFR Calculation					
BUN/Creatinine Radio					
Glucose					
POC Glucose					147 H
Lactic Acid					
Calcium					
POC WB Ioniz Calcium					
Phosphorus					
Magnesium	5.4 H	5.9 H	6.6 H	7.1 H	
Iron					
TIBC					
% Saturation					
Unsat Iron Binding					
Ferritin					
Total Bilirubin					
Direct Bilirubin					
Indirect Bilirubin					
AST					
ALT					
Alkaline Phosphatase					
C-Reactive Pro, Quant					
B-Natriuretic Peptide	215 H				
Total Protein					

Table 5: Flowsheet of the resolution of the hypermagnesemia without further hemodialysis when the catharsis was successful.

	4/30/13 07:10	4/30/13 07:10	4/30/13 07:10	4/30/13 16:34	4/30/13 16:34
Sodium	133				
Potassium	4.2			3.4 L	
Chloride	100				
Carbon Dioxide	22				
POC Total CO2					
Anion Gap	11				
BUN	49 H				
Creatinine	2.8 H				
GFR Calculation					
BUN/Creatinine Radio	17.5				
Glucose	143 H				
POC Glucose					
Lactic Acid					
Calcium	8.0 L				
POC WB Ioniz Calcium					0.97 L
Phosphorus	4.4			2.4 L	
Magnesium	5.3 H			3.6 H	
Iron					
TIBC					

% Saturation					
Unsat Iron Binding					
Ferritin					
Total Bilirubin					
Direct Bilirubin					
Indirect Bilirubin					
AST					
ALT					
Alkaline Phosphatase					
C-Reactive Pro, Quant					
B-Natriuretic Peptide			343 H		
Total Protein					

Table 6: Flowsheet of the resolution of the hypermagnesemia without further hemodialysis when the catharsis was successful.

	5/2/13 21:36	5/3/13 03:45	5/4/13 05:04	5/5/13 04:53	5/5/13 04:53
Sodium		136	139	142	
Potassium	3.4 L	3.9	3.2 L	3.3 L	
Chloride		99	102	104	
Carbon Dioxide		29	25	27	
POC Total CO2					
Anion Gap		8	12	11	
BUN		42 H	35 H	32 H	
Creatinine		0.9	0.8	0.8	
GFR Calculation		>60		>60	
BUN/Creatinine Radio		46.7 H	43.8 H	40.0 H	
Glucose		98	113 H	106	
POC Glucose					
Lactic Acid					
Calcium		8.6	8.3 L	8.0 L	
POC WB Ioniz Calcium					
Phosphorus	3.9	3.7		3.5	
Magnesium	2.9 H	2.7 H			
Iron					
TIBC					
% Saturation					
Unsat Iron Binding					
Ferritin					
Total Bilirubin					0.2
Direct Bilirubin					0.0
Indirect Bilirubin					0.0
AST					0.2
ALT					28
Alkaline Phosphatase					14
C-Reactive Pro, Quant					61
B-Natriuretic Peptide					
Total Protein					5.7 L

Table 7: Flowsheet of the resolution of the hypermagnesemia without further hemodialysis when the catharsis was successful.

	5/6/13 05:18	5/7/13 05:19	5/8/13 05:43	5/9/13 05:18	5/10/13 07:05
Sodium	143	140		138	139
Potassium	3.3 L	3.9	4.0	4.3	3.9
Chloride	108 H	107		108 H	109 H
Carbon Dioxide	25	24		21	22
POC Total CO_2					
Anion Gap	10	9		9	8

BUN	23	16		13	15
Creatinine	0.7	0.8		0.8	0.8
GFR Calculation	> 60	> 60			
BUN/Creatinine Radio	32.9 H	20.0		16.3	18.8
Glucose	112 H	109		113 H	107
POC Glucose					
Lactic Acid					
Calcium	8.0 L	8.0 L		8.5	8.2 L
POC WB Ioniz Calcium					
Phosphorus	2.7	2.9	3.1		
Magnesium	1.8		1.9		
Iron					
TIBC					
% Saturation					
Unsat Iron Binding					
Ferritin					
Total Bilirubin					
Direct Bilirubin					
Indirect Bilirubin					
AST					
ALT					
Alkaline Phosphatase					
C-Reactive Pro, Quant					
B-Natriuretic Peptide					
Total Protein					

States. Electrolyte surveillance and correction is one of the most common and important interventions made by our team. Finally, a review the literature with respect to the impact of electrolyte disorders on morbidity and mortality and such quality outcomes such as ICU and hospital length of stay was presented along with an illustrative case.

In conclusion, a quick summary of the salient features of this report is presented below:

Top Ten Features of the Workload of the Most Rural Tele-intensivist Care Program

1. Our tele-intensivist program is considered the most rural of similar programs in the USA.
2. We monitor 133 beds in 33 hospitals across a 6 state area.
3. Our program has been operating for 108 months.
4. The program increases throughput such that there are a high number of admissions per day.
5. Our program has the highest number of interventions per month (925).
6. Electrolyte management, acid-base surveillance and correction, and glucose control are the most frequent interventions across three categories of major, intermediate, and minor interventions.
7. Tele-intensivist care is an active, welcome, and needed service in the rural setting.
8. A rural environment likely has the most acceptance of input from a tele-intensivist service to improve quality measures in rural hospitals in a cost-effective manner.
9. Decisions as to when to transfer a patient to the tertiary care center can be a coordinated effort between the tele-intensivist and the primary care rural provider to facilitate transfer and to be sure transfer occurs in a timely rather than delayed manner.
10. The tele-intensivist service can provide expertise to keep many patients locally to avoid the large cost of ground or especially air transfer.

A critique of this report is that it is a purely descriptive work. The conclusions above are not based on proving a hypothesis. The goal of the information presented here is to catalogue and quantitate the daily work of intensivists managing seriously ill patients by telemedicine. Managing electrolytes is among the most common tasks performed repeatedly by the telemedicine staff. A brief review of several articles which have shown improved patient outcomes by electrolyte management is presented to suggest that the same would be true in these telemedicine efforts. Finally, an actual illustrative case report is presented reviewing the interaction of the rural tele-intensive care hub or center in the management of a severe electrolyte disorder (hypermagnesemia) in the patient at the rural site. The interaction led to transfer to the tertiary medical center for dialysis to correct the disorder and subsequent physiological consequences.

CONFLICTS OF INTEREST

The author declares no conflict of interest. The author wishes to thank the staff of physicians, nurses, and information clerks of the Avera eICU Care™ (T) program for the many years of dedication to advancing telehealth to the North Central region of the United States.

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