A prototype expert clinical decision support system to guide appropriate use of intravenous fluid during a national emergency

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Abstract: As demonstrated by the recent intravenous fluid shortage in the United States following Hurricane Helene in 2024, climate change threatens health system supply chains worldwide. This paper describes a prototype expert system that guides clinicians to use intravenous fluid appropriately, both during normal times and during periods of shortage. With its relative simplicity, it offers a model for a rapidly deployable tool, whether to conserve IVF during a critical shortage or to meet the needs of another, future medical supply emergency.

Keywords: expert system, clinical decision support, intravenous fluid, supply chain disruption, climate change

1 Background

Baxter Corporation produces 60% of the intravenous fluid (IVF) used in the U.S. at a single facility in North Cove, NC, USA[1]. Hurricane Helene caused significant damage to the manufacturing facility on September 28, 2024, markedly reducing the supply of IVF available to sustain normal U.S. hospital operations[2]. This has required hospitals to implement immediate IVF conservation and other, sometimes extreme measures (such as repurposing fluids typically used for dialysis to be irrigation fluids in operating rooms) in response[3]. Health systems have taken steps to increase awareness of the IVF shortage among staff, in the hope that clinicians will act more conscientiously about IVF use.

During this time of national IVF shortage, providing real-time and in-line clinical decision support to hospital physicians and other providers who order IVF will be critical to *enabling the use of IVF for appropriate clinical situations* and at the same time *conserving the overall supply of IVF*. Additionally, given that IVF management is not traditionally a topic that receives a great deal of attention in medicine, there is an opportunity to educate clinicians about appropriate IVF types and rates of administration for a variety of common clinical conditions.

Given the recency of the IVF crisis in the U.S., there is little published literature to guide health systems in their response. IVF algorithms exist, notably the NICE guidelines in the U.K., although even these well-considered guidelines have limitations[4]. First, they were designed for periods of normal operation, rather than emergency circumstances. Second, for expert guidance such as the NICE guidelines to be most useful, it must be transformed into actionable intelligence that can be efficiently integrated into clinical workflows. In a prior IVF shortage, at least one group attempted to provide ordering guidance to clinicians via an interruptive alert, but clinicians disregarded the alert guidance approximately 89% of the time[5].

More recently, Carr and colleagues reported that in response to the 2024 Baxter IVF shortage, a multifaceted IVF conservation approach reduced the volume of normal saline (NS) used by 52% and the volume of Lactated Ringer's (LR) used by 39%[6]. To date, no AI-based solutions have been proposed to address the 2024 IVF emergency.

This paper describes a prototype expert system that can guide clinicians to use appropriate types and volumes of IVF during the current crisis. The expert system aims to 1) better conserve the scarce IVF supply at hospitals and 2) offer recommendations for how clinicians can treat patients with IVF appropriately, even during a crisis. The prototype provides guidance for six common clinical conditions that require IVF: shock, rehydration, maintenance, contrast radiology studies, pancreatitis, and diabetic ketoacidosis (DKA). The expert system tailors IVF recommendations based on a hospital's IVF supply level as follows:

- Hospital is at green level (supplies are normal). At the green level, clinicians may order IVF without restrictions.
- Hospital is at yellow level (limited supply). At the yellow level, clinicians should practice modest conservation of IVF.
- Hospital is at red level (critically limited supply). At the red level, clinicians should exercise strict conservation of IVF.

2 Materials and Methods

This expert system is built using CLIPSPY which was run on a Jupyter Notebook (version 6.5.4). As noted, it was intended to provide evidence-based guidance about the two most commonly used IVF, NS and LR, and administration rates to the extent possible[7]. However, this objective was limited by the fact that for many clinical conditions, the ideal fluid type and administration volume has not been established. Clinical conditions addressed with this expert system and corresponding IVF guidance under normal conditions is provided below. There are no published guidelines about how to adjust these ideal-condition recommendations for emergencies in which IVF supplies are severely constrained.

2.1 Shock

The Society of Critical Care Medicine in its 2021 guidelines advise that patients with shock be administered at least 30ml/kg of intravenous crystalloid within the first 3 hours of resuscitation[8]. In addition, for patients with septic shock LR is preferred over NS for resuscitation[9]. Data indicates that in a critical care population generally, LR is associated with a lower rate of a composite outcome of death from any cause, initiation of dialysis, or persistent renal dysfunction compared to NS[10].

2.2 Maintenance

While explicit guidance about the type and rate of administration of IVF for maintenance purposes (that is, when a patient is temporarily ordered nothing by mouth) is quite limited, experiences across ED, surgical, and ICU settings suggest relative benefits to using balanced crystalloid fluids such as LR instead of NS[11].

2.3 Contrast radiology studies

Patients with an estimated Glomerular Filtration Rate (GFR) of less than 30ml/min/1.73m^2 who are undergoing radiology studies that require intravenous contrast should be treated with IVF to reduce the risk of developing contrast-associated acute kidney injury (CA-AKI)[12]. Isotonic fluid such as NS is typically preferred over hypotonic fluids such as ½ NS. While studies in this field offer conflicting results and guidance, an accepted regimen to prevent CA-AKI is 1 ml/kg/hour of NS starting 1 hour before the contrast study and extending for 6 hours following the conclusion of the study that requires intravenous contrast. However, fluid recommendations may vary from center to center.

2.4 Pancreatitis

In pancreatitis, evidence demonstrates that a moderate approach to IVF resuscitation is preferred over an aggressive one given that aggressive approaches are associated with higher rates of volume overload and longer hospital stays[13]. As such, a regimen of 10 ml/kg as an initial bolus is advised if a patient is clinically hypovolemic (may forego if a patient is normovolemic) followed by a rate of 1.5ml/kg/hour. Emerging evidence demonstrates that LR is clearly the preferred fluid for acute pancreatitis. Administration of LR to patients with acute pancreatitis was associated with decreased odds of developing moderately severe or severe pancreatitis compared to patients administered NS[14]. As a consequence, the most recent American College of Gastroenterology guidelines advise a moderate resuscitation with IVF and the use of LR over NS[15].

2.5 Diabetic ketoacidosis (DKA)

For DKA, too, LR has emerged as the preferred fluid over NS. One study reported that balanced IVF, including LR, were associated with a mean time of DKA resolution that was over 5 hours sooner than for patients treated with NS[16]. Earlier resolution of DKA with LR compared to NS was also observed in a multicenter trial of 771 patients[17]. LR is also associated with lower rates of hyperchloremia and greater improvement in renal function at 48 hours compared to NS in patients with DKA[18]. The 2024 American Diabetes Association consensus guidelines incorporate these findings, although they do counsel clinicians to use whatever fluid type is most readily available[19].

3 Design

This tool is a prototype expert system that can be accessed at `https://github.com/mcgreevj/BMIN-5200`. Like all expert systems, it has a user interface that in this case, is text based. The system also has an inference engine that is part of CLIPSPY as well as a knowledge base. The knowledge base consists of responses provided to questions asked of expert system users, where responses become case-specific facts. For example, if the user is asked to input the condition that requires IVF therapy, an answer of shock then becomes a fact in the knowledge base. An example of a fact template, one that can store the IVF supply status at the hospital, is shown in **Figure 1**.

```
#IVF supply template
DEFTEMPLATE_SUPPLY = """
(deftemplate supply
    (slot supply_status (type SYMBOL) (allowed-symbols green yellow red))
)
"""
env.build(DEFTEMPLATE_SUPPLY)
```

Figure 1: IVF supply deftemplate

The knowledge base also includes rules that make use of the facts obtained. Given that this prototype expert system is meant to be clinician-facing and fast to use, the number of questions posed to users was minimized to only those that are most important in order to generate an IVF recommendation. For example, given that the only well-accepted IVF to use for the contrast condition is NS, a rule is built into the system such that the clinician is spared the question about IVF choice. The system also makes use of forward chaining to develop new facts. For instance, for a subset of clinical conditions, IVF recommendations will change if the patient is known to have heart failure, a condition that predisposes to excess fluid accumulation that can become symptomatic (shortness of breath) and life-threatening (hypoxemia, impaired cardiac output). One rule in this expert system assesses if the patient is both greater than or equal to 50 years old (patients in this age group would be more likely to have heart failure) and has one of the conditions that would warrant adjustment in IVF administration rates in the event of heart failure. This rule, if satisfied, executes an additional query to the user asking if the patient has heart failure. Responses (yes or no) become new facts in the knowledge base that are later incorporated into IVF therapy recommendation rules.

A prompt map stores the questions that will be posed to system users if certain rules are executed. An initial rule executes the first queries that make use of the prompt map. Answers to these queries are stored in the deftemplates as facts.

IVF therapy rules in the expert system were designed after developing a therapy table (shown in **Figure 2** below) that inventories all possible clinical scenarios that the system can accommodate.

		IV Fluid Supply Level		
		GREEEN	YELLOW	RED
Condition	**Preferred fluid**	**Therapy recommendation_Green**	**Therapy recommendation_Yellow**	**Therapy recommendation_Red**
Shock	lr, ns	30ml/kg lr or ns bolus	30ml/kg lr or ns bolus	Consider vasopressor therapy. Consider 15-30ml/kg lr or ns bolus.
Adjust Shock for HF?	No	No	No	No
Rehydration	lr, ns	20ml/kg lr or ns bolus and reassess clinically.	20ml/kg lr or ns bolus and reassess clinically Consider oral rehydration if possible.	20ml/kg lr or ns bolus and reassess clinically Consider oral rehydration if possible.
Adjust Rehydration for HF?	Yes	15ml/kg lr or ns bolus and reassess clinically.	15ml/kg lr or ns bolus and reassess clinically. Consider oral rehydration if possible.	15ml/kg lr or ns bolus and reassess clinically. Consider oral rehydration if possible.
Maintenance	lr, ns	25ml/kg/day lr for up to 1 day and then reassess clinically.	25ml/kg/day lr for up to 1 day and then reassess clinically. Consider oral hydration if possible.	20ml/kg/day lr for up to 1 day and then reassess clinically. Consider oral hydration if possible.
Adjust Maintenance for HF?	Yes	15ml/kg/day lr for up to 1 day and then reassess clinically	15ml/kg/day lr for up to 1 day and then reassess clinically	15ml/kg/day lr for up to 1 day and then reassess clinically
Contrast	ns	1 ml/kg/hour ns starting 1 hour before contrast study and for 6 hours after contrast study	1 ml/kg/hour ns starting 1 hour before contrast study and for 6 hours after contrast study	0.5ml/kg/hr ns starting 1 hour before contrast study and for 6 hours after contrast study. Consider oral hydration if possible.
Adjust Contrast for HF?	No	No	No	No
Pancreatitis	lr, ns	10ml/kg bolus lr or ns then 1.5ml/kg/hr	10ml/kg bolus lr or ns then 1.5ml/kg/hr and reassess clinically at 6 hours	5ml/kg bolus lr or ns then 1ml/kg/hr and reassess clinically at 6 hours
Adjust Pancreatitis for HF?	Yes	10ml/kg bolus lr or ns then 1.5ml/kg/hr and reassess clinically at 6 hours	10ml/kg bolus lr or ns then 1.5ml/kg/hr and reassess clinically at 6 hours	5ml/kg bolus lr or ns then 1ml/kg/hr and reassess clinically at 6 hours
DKA	lr, ns	15-20 mL/kg of body weight per hour lr or ns for the first 1-2 hours, then adjust based on clinical status	15-20 mL/kg of body weight per hour lr or ns for the first 1-2 hours, then adjust based on clinical status	10-15 ml/kg of body weight per hour lr or ns for the first 1-2 hours, then adjust based on clinical status
Adjust DKA for HF?	No	No	No	No

Figure 2: IV fluid therapy recommendations by condition and supply level

4 Demonstration

This prototype expert system is built and available for use. It has been tested with simulated patient data for all possible combinations of scenarios including younger vs. older age, green, yellow, or red IVF supply status, clinical condition, and heart failure status. In total, there are 54 possible scenarios that this expert system can accommodate. While the system passed initial testing for many of these scenarios, for some it did not. These scenarios were marked as failed tests because no IVF guidance printed after all data had been entered. Testing failures prompted inspection of the system test results for patterns that could pinpoint the cause of the failures. Rules were adjusted accordingly. After troubleshooting, all of these scenarios that initially failed successfully passed testing in round 2.

When executed, this expert system prompts users to answer selected questions via a text-based interface. Based on answers to those questions, the system generates a recommendation for IVF as shown in **Figure 3**.

```
Enter patient name: Tony
Enter patient age (in years): 35
What is the indication for IV fluid? (shock rehydration maintenance contrast pancreatitis dka): shock
What is the current IV fluid supply level? (green, yellow, or red): green

Given the indication selected, you may choose a fluid type.

Enter the desired IV fluid type (either lr or ns): lr

__________
For Tony for condition shock recommend 30ml/kg lr or ns bolus
**lr is preferred**
__________
```

Figure 3: Expert system user interface, query responses, and resultant IVF recommendation

Figure 4 shows that the fact base can also be queried.

```
print_facts(env)

(hf (hf_status unknown))
(patient (name_is "Tony") (age_is 35))
(indication (fluid_indication shock))
(supply (supply_status green))
(fluid (fluid_type lr))
Total facts: 5
```

Figure 4: Query of fact base

As noted, the system makes use of forward chaining. Using the forward chaining rule for heart failure, for patients aged 50 and above with relevant clinical conditions, the user will be prompted to enter a heart failure status in addition to the standard questions noted in **Figure 3**.

Depending on the heart failure status, the clinical condition needing IVF, and the IVF supply status, a tailored recommendation will be presented to the user as shown in **Figure 5**.

```
__________
For Sharon for condition rehydration recommend 15ml/kg lr or ns bolus and reassess clinically. Consider oral rehydration if pos
sible.
 **lr preferred and use caution with iv fluids - heart failure patient**
__________
```

Figure 5: IVF recommendation tailored for condition, heart failure status, and IVF supply level

5 Discussion

5.1 Advantages and disadvantages

5.1.1 Advantages

This expert system offers a number of advantages to patients, clinicians, and hospitals. It provides real-time therapy guidance based on condition, patient factors, and IVF supply level. The system can help clinicians care for patients appropriately at the same time that it can conserve crucial supplies of IVF in an emergency. It serves not only as a therapy recommendation tool, but as an educational module given that IVF suggestions are as evidence-based as possible. The relative simplicity of this system is one of its advantages. This is important because it demonstrates that such a system could be developed and deployed rapidly in an emergency such as the current IVF crisis.

5.1.2 Disadvantages

This expert system is not currently integrated with the EHR nor within clinical workflows. As such, it faces the same risks that all standalone systems face – that it may not be adopted by busy clinicians. Another limitation of this system is that guidance for yellow/red IVF administration is not evidence-based and is likely to vary site to site and from expert to expert given the unprecedented nature of this IVF emergency. As such, the transferability of the knowledge in this system from one health system to another may be limited. Like any expert system, guidance may change over time and this system too, will require ongoing maintenance by a content expert. Such maintenance would be important to update the logic about IVF types and administration rates, for example. The system itself requires care to assure it is providing the best, most evidence-based recommendations possible. As a prototype, this system does not currently offer a rationale for each recommendation nor a way to query the evidence base on which the system's recommendations are based, both of which would be desirable features, similar to those found in the MYCIN system developed by Shortliffe and colleagues[20].

5.2 Recommended improvements for later versions of the expert system

Future versions of this expert system could minimize clinician data entry by integrating EHR data, such as patient weight in kilograms, vital sign measurements, lab results such as serum creatinine, and the exact volume of fluid administered. In addition, the system could integrate with the hospital pharmacy to track the current IVF inventory and establish supply levels (green, yellow, red) without prompting clinicians to do so. A future version of this system would also integrate with clinician ordering screens, to facilitate use of its guidance in real-time and within clinicians' workflows, in an effort to promote widespread adoption. Lastly, a future version could accommodate clinical uncertainty, such as in cases where a patient's heart failure status is unknown, as might be the case for a newly arrived patient in an emergency room.

6 Conclusions

This prototype expert system can address key needs during an IVF emergency, such as the one happening in 2025 in the U.S. It can guide clinicians to order evidence-based fluids, wherever possible, enabling them to provide high-quality care, even during a crisis. At the same time, this system provides hospitals with a mechanism to conserve scarce IVF resources. By using forward chaining to prompt additional questions only when necessary, the system minimizes the need for clinician data entry, thereby improving its chances of clinician adoption. In the future, the system's functionality could be expanded and usability improved to make the user experience more positive. As climate change continues to disrupt health care supplies worldwide, health care organizations could develop relatively straightforward systems like this one and deploy them rapidly in response to a future emergency.

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