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

John D. McGreevey III, MD[1]

[1]**Perelman School of Medicine at the University of Pennsylvania, Philadelphia, PA, USA**

1 Background

Baxter Corporation produces 60% of the intravenous fluid (IVF) used in the U.S. at a single facility in North Cove, NC[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 like Penn Medicine have taken steps to increase awareness of the IVF shortage among staff, in the hope that clinicians will act more conscientiously about IVF use. **Figure 1** shows an image of the logon screen to PennChart, the Penn Medicine electronic health record (EHR), that was used as one channel for communicating emergency measures to frontline clinicians.

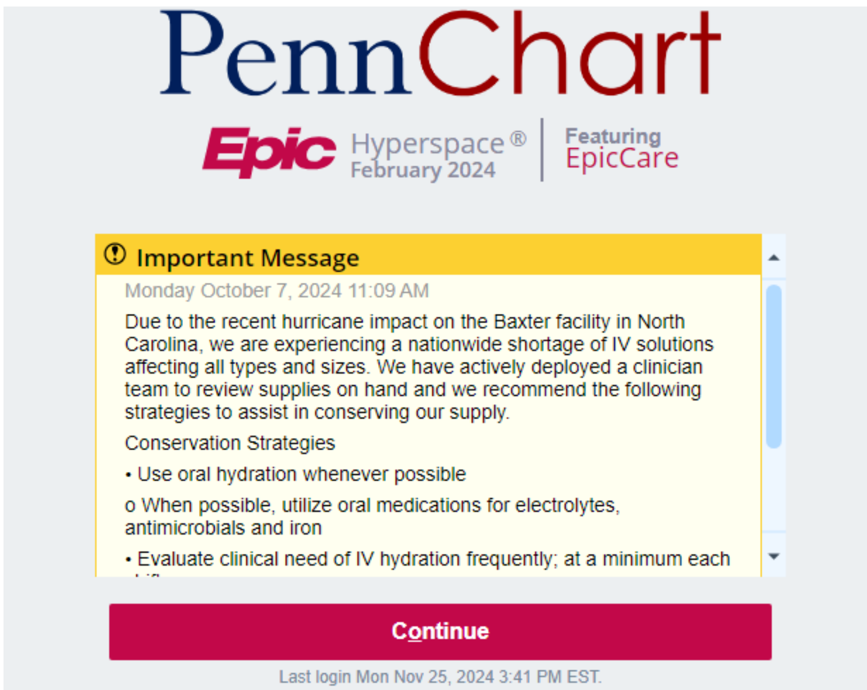

Figure 1: PennChart logon screen communicating the IVF emergency and conservation strategies

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.

The two most widely used types of IVF are normal saline (NS) and Lactated Ringer's (LR), given that they have a broad range of clinical applications[4].

Given this national IVF crisis is so recent, there is little published literature to guide appropriate health system responses. Algorithms exist for the use of IVF, notably the NICE guidelines in the U.K., although even these well-considered guidelines have limitations[5]. First, they were designed for periods of normal operation, rather than emergency circumstances. Second, at five pages of text and flowcharts, they are complex to operationalize at the frontlines of care without spending a substantial amount of time to read and understand them. For expert guidance such as the NICE guidelines to be useful, it must be transformed into actionable intelligence that can be efficiently integrated into clinical workflows. Some authors have attempted to provide in-line guidance to clinicians during earlier times of IVF shortage, notably by leveraging a commonly used tool in electronic health records, an interruptive alert[6]. In one case, the alert suggested that clinicians replace intravenous magnesium (which requires a diluent of IVF) with an oral magnesium supplement. Despite the alert, clinicians ordered oral magnesium or abandoned their plan to replete magnesium entirely only 11% of the time. Put another way, clinicians disregarded the alert recommendation approximately 89% of the time that the IVF-conserving alert fired.

More recently, Carr and colleagues reported that in response to the 2024 Baxter IVF shortage, a multifaceted IVF conservation approach was able to reduce the volume of NS used by 52% and the volume of LR used by 39%[7]. To date, no AI-based solutions have been proposed to address the 2024 IVF emergency.

This final project aims to create a prototype expert system that can guide clinicians to use appropriate types (notably normal saline and Lactated Ringer's) and volumes of IVF during this crisis. The expert system aims to 1) better conserve the scarce IVF supply at U.S. 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 IVF types and administration rates to the extent possible. While explicit guidance about IVF types and administration rates is somewhat limited in the literature, a summary of recommendations for the conditions that have IVF guidance available is provided below. It is worth noting that all of the following guidance assumes ideal conditions (i.e. unlimited IVF supply). 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 1ml/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, although exact fluid recommendations may vary from center to center.

2.4 Pancreatitis

In pancreatitis, evidence demonstrates that a moderate IVF resuscitation approach is preferred over an aggressive resuscitation approach given that aggressive approaches are associated with higher rates of volume overload and longer hospital stays[13]. As such, a regimen of 10ml/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 2**.

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

Figure 2: 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 a recommended therapy. 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. **Figure 3** shows this heart failure forward chaining rule.

```
#Rule to check patients over 50 for possible HF, as HF may require more conservative fluid
#Limited to indications for which ivf recommendation would be adjusted for HF
DEFRULE_HF_READ = """
(defrule HF_READ ; does this patient have HF?
    (logical
        (patient (age_is ?age))
        (test(>= ?age 50))
        (or
            (indication (fluid_indication rehydration))
            (indication (fluid_indication maintenance))
            (indication (fluid_indication pancreatitis))
        )
    )

    =>

    (read_assert hf)
)
"""
env.build(DEFRULE_HF_READ)
```

Figure 3: Heart failure defrule

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. **Figure 4** shows the prompt map for this expert system and the initial rule that initiates queries to users.

```
#Prompt map
prompt_map = {
    "patient:name_is": "Enter patient name: ",
    "patient:age_is": "Enter patient age (in years): ",
    "fluid:fluid_type": "Enter the desired IV fluid type (either lr or ns): ",
    "supply:supply_status": "What is the current IV fluid supply level? (green, yellow, or red): ",
    "indication:fluid_indication": "What is the indication for IV fluid? (shock rehydration maintenance contrast pancreatitis dk
    "hf:hf_status": "Does this patient have a history of or suspicion for heart failure? (yes/no): "
}
build_read_assert(env, prompt_map)
```

```
#INITIAL QUERY DEFRULE
DEFRULE_INITIAL_QUERY = """
(defrule initial_query
    =>
    (read_assert patient)
    (read_assert indication)
    (read_assert supply)
)
"""
env.build(DEFRULE_INITIAL_QUERY)
```

Figure 4: Expert system prompt map and initial query defrule

IVF therapy rules in the expert system were designed after developing a therapy table (shown in **Figure 5** 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 5: IV fluid therapy recommendations by condition and supply level

An example of such a rule is one for the clinical condition of shock when IVF supply levels are either green or yellow (see **Figure 6**).

```
#Defule for green/yellow/shock #1
DEFRULE_GREEN_YELLOW_SHOCK = """
(defrule green_ns_shock "Rule to assess if green/yellow/shock criteria met"
    (logical
        (patient (name_is ?name))
        (patient (age_is ?age))
        (supply (supply_status ?supply))
        (fluid (fluid_type ?fluid))
        (indication (fluid_indication ?indication))

        (and
            (indication (fluid_indication shock)) ; fluid indication is shock
            (or
                (supply (supply_status green)) ; green supply status
                (supply (supply_status yellow)); yellow supply status
            )

        )
    )


    =>

    (println "___________")
    (println "For " ?name " for condition " ?indication " recommend 30ml/kg lr or ns bolus")
    (println "**lr is preferred**")
    (println "___________")
)
"""

env.build(DEFRULE_GREEN_YELLOW_SHOCK)
```

Figure 6: Defrule for shock where supply = Green or Yellow

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. An example of testing results for the scenarios relevant to the rehydration condition is shown below in **Figure 7**, noting some failed scenarios in testing round 1. These scenarios were marked as failed tests because no IVF guidance printed after all data had been entered. After troubleshooting, all of these scenarios that initially failed successfully passed testing in round 2.

Condition	Supply status	Age testing > or <50	HF status, if applicable	1st round test	2nd round test
Rehydration	Green	Age55	noHF	pass	
Rehydration	Yellow	Age 55	noHF	pass	
Rehydration	Red	Age 55	noHF	pass	
Rehydration	Green	Age55	wHF	pass	
Rehydration	Yellow	Age 55	wHF	pass	
Rehydration	Red	Age 55	wHF	pass	
Rehydration	Green	Age 35		fail	pass
Rehydration	Yellow	Age 35		fail	pass
Rehydration	Red	Age 35		fail	pass

Figure 7: Sample test scenarios and results

Testing failures prompted inspection of the system test results for patterns that could pinpoint the cause of the failures. Rules were adjusted accordingly and on subsequent testing, the expert system provided correct IVF therapy guidance for each of the 54 scenarios. While not yet live in a clinical environment, there is the potential to make a prototype system such as this one available for clinical use.

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 8**.

```
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 8: Expert system user interface, query responses, and resultant IVF recommendation

Figure 9 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 9: 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, either yes or no as shown in **Figure 10**.

```
Enter patient name: Sharon
Enter patient age (in years): 78
What is the indication for IV fluid? (shock rehydration maintenance contrast pancreatitis dka): rehydration
What is the current IV fluid supply level? (green, yellow, or red): red
Does this patient have a history of or suspicion for heart failure? (yes/no): yes
```

Figure 10: Illustration of forward chaining in the user interface

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 11**.

```
__________
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 11: IVF recommendation tailored for condition, heart failure status, and IVF supply level

5 Discussion

5.1 Challenges in developing the system

Naturally, creating any complex system comes with challenges. A first challenge was the need to balance creating a basic, functional prototype with the desire to make it a robust and sophisticated system. The system could always be better and offer enhanced functionality, such as calculating exact doses of IVF based on patient weight for fluids that have weight-based administration rates. However, ultimately, a decision was made to prioritize creating a functional system over a system that had every possible desirable feature. A second challenge was determining how to minimize user queries. As a system intended for clinical use, it is important to ask clinicians for the minimum necessary information, recognizing that time is precious when caring for patients. Clinicians will be unlikely to adopt a system that is cumbersome and that requires too much data entry. In addition to minimizing user questions, it was important to ask questions that were relevant to the clinical context. For example, the heart failure status question only presents for patients at higher risk of heart failure and only for conditions where heart failure presence or absence would alter IVF therapy recommendations. Development of this system also required meticulous care in the creation and updating of rules. The expert system contains 18 rules that drive IVF recommendations. It was easy to make a mistake in naming the rule or in failing to update a critical line of code. Mistakes made in the course of creating this system served as a reminder that such systems can be powerful, but they can also be brittle and broken by human error. In a similar vein, there were challenges with anomalies in the creation of this system. For example, with some troubleshooting, the system eventually passed when tested against all clinical scenarios during testing in week 1. Then in week 2 when retested, the system began giving two, incompatible IVF recommendations for some patients (example: a recommendation for a patient with heart failure and another recommendation for a patient without heart failure). Another example of anomalous behavior was that in week 1, questions appeared in the correct sequence, with the heart failure question, if relevant, appearing prior to the desired IVF question. In week 2, however, the desired IVF fluid question sporadically appeared *prior* to the heart failure question. These unexpected findings required several hours of investigation, analysis, and troubleshooting to correct. Lastly, this system required many rounds of testing, both as each rule was added and then once the entire system was built. Testing required advance planning and the development of a testing rubric that accounted for all possible scenarios that the expert system might encounter. However, this incremental approach to build and testing reduced the likelihood of errors at the end of the development process, given that each component of the system had been tested throughout the course of development.

5.2 Advantages and disadvantages

5.2.1 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. This system has potential to be integrated with the EHR, both in terms of data acquisition and embedding within ordering modules to facilitate use and usefulness. In future iterations, this system has the potential to pose the minimum necessary questions of clinicians and to have expanded capabilities. For example, the system could query the EHR about a particular patient's renal function to determine if IVF are indicated prior to a contrast radiology study. Such harnessing of EHR data would allow the system to have additional opportunities for forward chaining as well as improved usability, given that it would minimize data-entry burdens. 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.

5.2.2 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]. Lastly, there is the open question about the utility of such expert systems. Is such a system, as useful as it may be, worth the time and effort to build, deploy, and maintain for an emergency that is hopefully time-limited? Such a question becomes even more challenging to answer when the duration of an emergency is unclear, such as the anticipated duration of the COVID-19 pandemic as of March 2020, which would have been nearly impossible to predict at the time.

5.3 Recommended improvements for later versions of the expert system

Recognizing that this is an initial prototype, future versions of this system can incorporate additional functionalities including potentially: 1. The ability to manually input the volume of IVF available on a particular day at a particular hospital, such as 800 liters of LR. Alternatively, the expert system might be able to access central pharmacy data directly to determine the available volume of IVF on a particular day. 2. Based on item 1 above, the system will have the ability to determine the IVF supply status (green, yellow, red) without prompting the clinician for that information. Such a status could be displayed to clinicians within ordering screens in the future, to provide situational awareness of supply limitations at the time of IVF ordering. 3. The ability to calculate exact administration rates and volumes using data in the EHR, such as patient weight in kilograms, vital sign measurements, and lab results such as serum creatinine and associated calculations such as estimated glomerular filtration rate. 4. The ability to deduct an ordered volume of IVF from the main hospital supply, to provide real-time awareness to pharmacy leadership of the remaining IVF available at the entity. 5. As noted previously, the integration of this expert system prototype with the CPOE component of the EHR, so that the guidance this system offers can be incorporated within IVF ordering screens that clinicians use. This is likely to enhance the uptake of the ordering guidance that this expert system provides, given that it will better integrate into clinical workflows. 6. The ability for users to query the system about why certain recommendations were made and for relevant reference materials (if they exist) to be cited as evidence for the recommendations. 7. A later version of this expert system would also allow for clinician 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. 8. A later version of this expert system will have enhanced usability. For example, it will enable error handling and user recovery when an error is made, such as mis-entered data. At present, this initial prototype does not include response validation nor error handling.

6 Conclusions

This prototype expert system can meet key needs during an IVF emergency, such as the one happening now in the United States. 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. While in its prototype form this system has disadvantages, such as lack of integration into EHRs and clinical workflows and limited functionality, it holds potential to provide value in the current and future IVF crises. It leverages forward chaining to prompt new questions to appear dynamically for clinicians only when necessary to formulate an IVF recommendation. In so doing, it minimizes data entry burden on clinicians. As noted, its functionality could be expanded and usability improved to make the user experience more positive. Like all expert systems, this one depends on experts who can inform the system's initial content and maintain it over time as evidence and guidelines change. Importantly during a national crisis, the portability of such a system from one organization to another depends on inter-organization agreement about expert system rules and therapy recommendations. The relatively simple build means that health care organizations could develop systems like this one and deploy them rapidly in response to an emergency.

References

1. AHA letter to president urges administration to take immediate action to address IV solution supply shortage as a result of Helene. AHA News: American Hospital Association [Internet]. 2024 Oct 7 [cited 2024 Dec 2]; Available from: https://www.aha.org/news/headline/2024-10-07-aha-letter-president-urges-administration-take-immediate-action-address-iv-solution-supply-shortage
2. Jewett C. U.S. races to replenish storm-battered supplies of IV fluids at hospitals. The New York Times [Internet]. 2024 Oct 9 [cited 2024 Dec 2]; Available from: https://www.nytimes.com/2024/10/09/health/hurricane-helene-iv-shortages.html
3. Murphy T. Hospitals' IV fluid shortage may impact surgeries for weeks. Associated Press [Internet]. 2024 Oct 22 [cited 2024 Nov 23]; Available from: https://apnews.com/article/baxter-iv-fluids-supply-hospitals-helene-5859c9ca5fa168b71a5d8c370a47365c
4. Tinawi M. New trends in the utilization of intravenous fluids. Cureus [Internet]. 2021 Apr 21 [cited 2024 Dec 2]; Available from: https://www.cureus.com/articles/56838-new-trends-in-the-utilization-of-intravenous-fluids
5. Intravenous fluid therapy in adults in hospital, NICE clinical guideline 174 [Internet]. National Institute for Health and Care Excellence; 2016. Available from: https://www.nice.org.uk/guidance/cg174/resources/intravenous-fluid-therapy-in-adults-in-hospital-algorithm-poster-set-191627821
6. Sandler M, Cavanaugh J, Walton T, Cavendish L, Shah K. Management of an i.v. fluid shortage through use of electronic medical record alerts. American Journal of Health-System Pharmacy. 2020 Mar 24;77(7):546–51.
7. Carr J, Orvin D. Large-volume intravenous fluid use before and after implementation of a fluid conservation strategy. American Journal of Health-System Pharmacy. 2024 Oct 25;zxae330.
8. Evans L, Rhodes A, Alhazzani W, Antonelli M, Coopersmith CM, French C, et al. Surviving Sepsis Campaign: International guidelines for management of sepsis and septic shock 2021. Critical Care Medicine. 2021 Nov;49(11):e1063–143.
9. Tseng CH, Chen TT, Chan MC, Chen KY, Wu SM, Shih MC, et al. Impact of comorbidities on beneficial effect of lactated ringers vs. saline in sepsis patients. Front Med. 2021 Dec 13;8:758902.
10. Semler MW, Self WH, Wanderer JP, Ehrenfeld JM, Wang L, Byrne DW, et al. Balanced crystalloids versus saline in critically ill adults. N Engl J Med. 2018 Mar;378(9):829–39.
11. Semler MW, Kellum JA. Balanced crystalloid solutions. Am J Respir Crit Care Med. 2019 Apr 15;199(8):952–60.
12. Rudnick MR, Fay K, Wahba IM. Fluid administration strategies for the prevention of contrast-associated acute kidney injury. Current Opinion in Nephrology and Hypertension. 2022 Sep;31(5):414–24.
13. de-Madaria E, Buxbaum JL, Maisonneuve P, García García De Paredes A, Zapater P, Guilabert L, et al. Aggressive or moderate fluid resuscitation in acute pancreatitis. N Engl J Med. 2022 Sep 15;387(11):989–1000.
14. Lee PJ, Culp S, Kamal A, Paragomi P, Pothoulakis I, Talukdar R, et al. Lactated ringers use in the first 24 hours of hospitalization is associated with improved outcomes in 999 patients with acute pancreatitis. Am J Gastroenterol. 2023 Dec;118(12):2258–66.
15. Tenner S, Vege SS, Sheth SG, Sauer B, Yang A, Conwell DL, et al. American College of Gastroenterology guidelines: Management of acute pancreatitis. Am J Gastroenterol. 2024 Mar;119(3):419–37.
16. Szabó GV, Szigetváry C, Turan C, Engh MA, Terebessy T, Fazekas A, et al. Fluid resuscitation with balanced electrolyte solutions results in faster resolution of diabetic ketoacidosis than with 0.9
17. Jamison A, Mohamed A, Chedester C, Klindworth K, Hamarshi M, Sembroski E. Lactated ringer's versus normal saline in the management of acute diabetic ketoacidosis (RINSE-DKA). Pharmacotherapy. 2024 Aug;44(8):623–30.
18. Carrillo AR, Elwood K, Werth C, Mitchell J, Sarangarm P. Balanced crystalloid versus normal saline as resuscitative fluid in diabetic ketoacidosis. Ann Pharmacother. 2022 Sep;56(9):998–1006.

19. Umpierrez GE, Davis GM, ElSayed NA, Fadini GP, Galindo RJ, Hirsch IB, et al. Hyperglycemic crises in adults with diabetes: a consensus report. Diabetes Care. 2024 Aug 1;47(8):1257–75.

20. Shortliffe EH, Axline SG, Buchanan BG, Merigan TC, Cohen SN. An artificial intelligence program to advise physicians regarding antimicrobial therapy. Computers and Biomedical Research. 1973 Dec;6(6):544–60.