Article published online: 2023-01-11

User-Centered Design to Reduce Inappropriate Blood Transfusion Orders

Brad Morse[1] Tyler Anstett[2] Neelam Mistry[2] Samuel Porter[2] Sharon Pincus[3] Chen-Tan Lin[1] Sylvie Novins-Montague[3] P. Michael Ho[4]

[1] Department of Medicine, Division of General Internal Medicine, University of Colorado School of Medicine, Aurora, Colorado, United States
[2] Department of Medicine, Division Hospital Medicine, University of Colorado School of Medicine, Aurora, Colorado, United States
[3] Adult & Child Center for Outcomes Research & Delivery Science/The NavLab, University of Colorado Anschutz Medical Campus, Aurora, Colorado, United States
[4] Department of Medicine, Division of Cardiology, University of Colorado School of Medicine, Aurora, Colorado, United States

Address for correspondence Brad Morse, PhD, MA, Department of Medicine, Division of General Internal Medicine, University of Colorado School of Medicine, 1890 N Revere Ct, Aurora, CO 80045, United States (e-mail: brad.morse@cuanschutz.edu).

Appl Clin Inform 2023;14:28–36.

Abstract

Background To improve blood transfusion practices, we applied user-centered design (UCD) to evaluate potential changes to blood transfusion orders.

Objectives The aim of the study is to build effective transfusion orders with different designs to improve guideline adherence.

Methods We developed three different versions of transfusion orders that varied how information was presented to clinicians ordering blood transfusions. We engaged 14 clinicians (residents, advanced practice providers [APPs], and attending physicians) from different specialties. We used the think aloud technique and rapid qualitative analysis to generate themes to incorporate into our modified orders.

Results Most end-users who participated in the semi-structured interviews preferred the interruptive alert design plus behavioral nudges ($n = 8/14$, 57%). The predominant rationale was that the in-line alert was not visually effective in capturing the end-user's attention, while the interruptive alert forced a brief stop in the workflow to consider the guidelines. All users supported the general improvements, though for different reasons, and as a result, the general improvements remained in the designs for the forthcoming trial.

Conclusion The user experience uncovered through the think aloud approach produced a clear and rich understanding of potentially confounding factors in the initial design of different intervention versions. Input from end-users guided the creation of all three designs so each was addressing human factors with parity, which ensured that the results of our study reflected differences in interruptive properties of the alerts and not differences in design.

Keywords

- user-centered design
- think aloud
- nudge
- EHR
- user experience
- transfusion

received
July 28, 2022
accepted after revision
October 17, 2022

DOI https://doi.org/10.1055/s-0042-1759866.
ISSN 1869-0327.

Georg Thieme Verlag KG, Rüdigerstraße 14, 70469 Stuttgart, Germany

Background and Significance

Clinical decision support (CDS) tools help improve patient safety and reduce variability in care. Still, there are limitations to their use[1] and some questions remain about the best ways to implement them. User-centered design (UCD) integrates the user in the solution design process,[2] using their direct feedback to optimize the design of an intervention. Some benefits of implementing a UCD approach include gaining buy-in from intended users, domain knowledge that informs the design, and tacit knowledge that users bring to the table in the design process.[3,4]

At our institution, we are studying the effects of different CDS designs on quality outcome measures, specifically on blood transfusion rates. Though a life-saving treatment for some patients, transfusions of blood products can result in patient harm and excess costs for health systems[5–9] when used indiscriminately. Optimal blood product utilization requires a balance between clinical benefit, costs, and risks associated with transfusions, which is why guidelines strongly recommend a "restrictive" RBC transfusion threshold of a hemoglobin (Hgb) of 7 g/dL for most hospitalized adult patients,[5,10,11] although compliance with transfusions guidelines is poor.[12] Based on others' successful quality improvement (QI) projects,[13–15] we created a CDS system targeted to computerized order entry to curb guideline-discordant transfusions at our institution.

This report details how we used UCD to build three distinct CDS designs. In contrast to previous studies that tested a single redesigned CDS in the electronic health record (EHR), we set out to study the comparative effectiveness of distinctive designs. We are deploying these three versions in a randomized fashion. Those results will be reported in a separate manuscript.

Objectives

The objective of this study was to integrate users' insights on the development of three different blood transfusion orders and understand how users experienced all three designs, identify pain points, and streamline the workflow. This allowed us to ensure the experimental arm designs were optimized for users and distinctive for comparison.

Methods

This manuscript focused on our use of UCD to optimize the three different versions of our intervention as follows: (1) version A: No Alert, (2) version B: Noninterruptive Alert, and (3) version C: Interruptive Alert. The No Alert version included only the general improvements described below but did not include any alerts. The Noninterruptive Alert version included a noninterruptive text alert detailing evidence-based transfusion recommendations that appeared if the patient's most recent hemoglobin level was above 6.9 g/dL. Finally, the Interruptive Alert version also included an alert detailing evidence-based transfusion recommendations that appeared if the patient's most recent hemoglobin level was above 6.9 g/dL but, in contrast to the noninterruptive alert, this version had an interruptive "pop-up" alert that appeared when the user chose to transfuse patients. This alert offered users the option to remove the order which resulted in no blood product being ordered. Alternatively, users could continue to order blood and were asked to select the reason for proceeding with the intended order with the selections reflective of the guideline indications for blood transfusions.

In addition to different alert mechanisms, we also made general improvements (from baseline) to each version of the intervention. At our institution, transfusing blood requires two orders from the clinician: prepare order and transfuse order. The prepare order directs the blood bank to prepare the unit of blood for transfusion. The transfuse order instructs the nurse to administer the blood, once received from the Blood Bank. The general improvements incorporated into each of the intervention versions include changes to both the prepare and transfuse orders (►Figs. 1 and 2). Changes to the prepare order included removing the indications and the multiunit prepare buttons. Changes to the transfuse order included removing the multi-unit transfusion buttons and adding guideline-concordant transfusion indication options. These changes used behavioral nudges to guide users to transfuse according to guidelines. A behavioral nudge is a minor change in framing choice that predictively alters people's behavior.[16] These changes were intended to be more intuitive for ordering clinicians and to reduce the number of clicks, decisions, and overall cognitive load. Additionally, by automatically choosing one unit to transfuse, eliminating readily available options for multi-unit transfusions (adding an extra step to transfuse more than one unit at a time), and forcing clinicians to choose from a list of guideline-concordant indications, these changes incorporate behavioral nudges to encourage clinicians to order within guidelines. Using behavioral nudges was a key guiding principle for this redesign.

The setting was the University of Colorado Hospital, an urban academic medical center with approximately 100,000 units of nonoperative units of blood ordered annually. We recruited 14 clinicians to interact with the orders while keeping a clinical vignette in mind, allowing the users to interact with the orders in a realistic setting and provide feedback on order usability and user experience.

We tested all three alternative versions (A, B, and C) of the new orders described above using the think aloud approach. During think aloud assessment, we conducted an integrated semi-structured interview for additional feedback. Additionally, six specific metrics were coded during the interaction to inform the preferences of our users that we described with descriptive statistics.

Subjects and Recruitment

We recruited 14 clinicians who consistently utilized the EHR (Epic Systems Corporation, Verona Wisconsin, United States) blood transfusion orders in their routine practice. We excluded clinicians that do not frequently place blood transfusion orders. Potential participants were identified by research project staff. We recruited participants by email

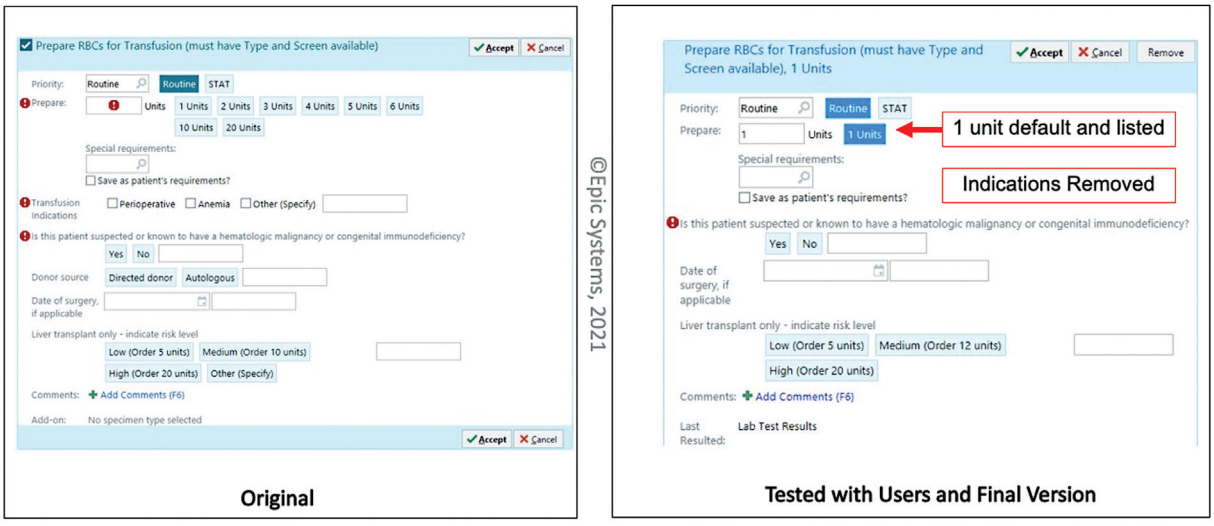

Fig. 1 Prepare order – original and UCD final version. Screenshots of the original and tested/final versions of the Prepare Order with changes detailed including removing the multiunit options for selection, defaulting the selection to one unit, and removing the nonguideline-based indications. UCD, user-centered design.

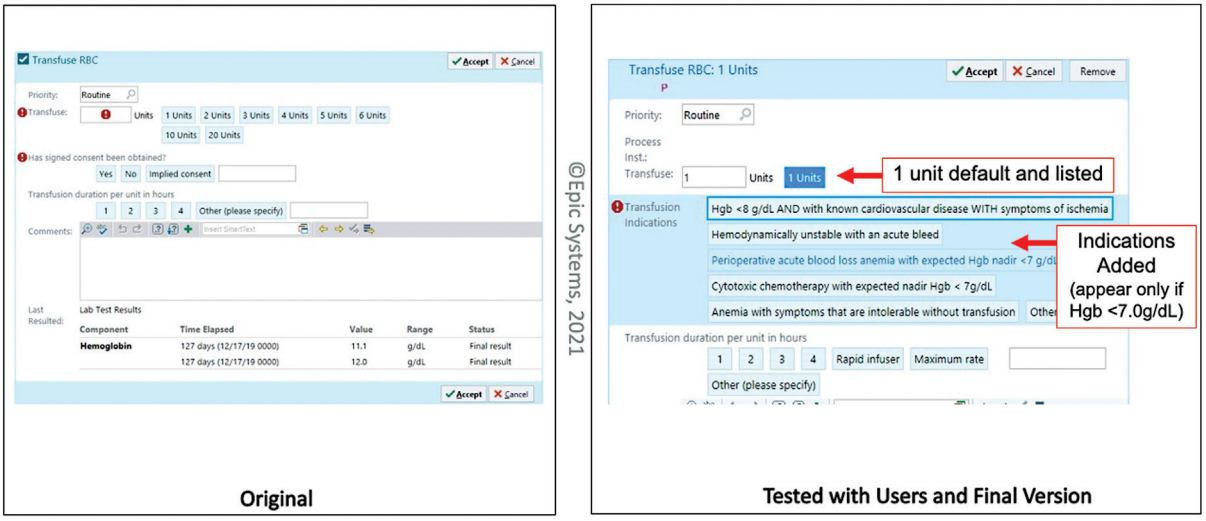

Fig. 2 Transfuse order—original and UCD final version. Original and UCD tested/final version (all arms). Screenshots of the original and tested/final versions of the transfuse order with changes detailed including removing the multi-unit options for selection, defaulting the selection to 1 unit, and adding guideline-based indications. Note: in our final version implemented in our eventual trial, the indications only appear if the pre-Hgb is less than 7.0 g/dL, a change suggested by user in UCD testing. Hgb, hemoglobin; UCD, user-centered design.

invitation. We extended invitations to additional clinicians as suggested by participants. A purposive sampling framework[17] was used to ensure experienced-based insights on the different order designs.

We invited a diverse set of research participants to ensure a dissimilar set of perspectives and user needs, including participants from Emergency Medicine, Bone Marrow Transplant, General Surgery, Hospital Medicine, Surgical ICU, Medical ICU, Medicine subspecialists, and Orthopedic surgery (►**Table 1**). Recruitment continued until enough clinicians agreed to be in the study to reach qualitative observational saturation in the sample. The goal was to have enough participants interact with the orders to get a breadth of insight and continue until we did not hear or observe new perspectives during the think aloud protocol. Participants were not compensated for their participation in this study. Our local IRB designated this as a QI effort, nonhuman subject research.

User-Centered Design Sessions

The UCD sessions were approximately 45 minutes each, conducted virtually using Zoom video conferencing. We first communicated to the research participants that the work being conducted was considered QI and that no consent was needed. We did not collect any personal health information during the UCD sessions. Each participant was asked if they would give their permission for the session to be recorded; all participants provided permission for the session to be recorded. The goals of the session were described to each of the participants. We outlined the structure of the session,

Table 1 Characteristics of study participants

Clinical service	
Medicine	7 (50%)
Surgery	5 (36%)
Emergency medicine	2 (14%)
Clinical role	
Attending	3 (21%)
APP	7 (50%)
Resident/fellow	4 (29%)
Gender	
Male	7 (50%)
Female	7 (50%)

Abbreviation: APP, advanced practice provider.

including the current state and exposure to three different test versions of the blood transfusion orders without providing details of the changes.

Before the think aloud began, we instructed participants to verbalize their decision-making and their thought process in line with the think aloud methodology.[18] The think aloud methodology requires participants to verbalize their cognitive decision-making as they moved through the task. This approach helps identify affordances, hindrances, and pain points of the usability of the task's user interface. If participants proceeded without thinking aloud, we prompted participants to pause and verbalize their thought processes so we could collect their insights.

We first instructed participants to read a prepared clinical vignette inspired by actual cases from the teams' clinical experience. The case was specifically written to direct participants to order a blood transfusion against generally accepted clinical guidelines. Participants were asked to keep this clinical case in mind when placing orders in each of the provided versions. Participants were then asked to place orders using the current order to ensure maximal proximal familiarity. We then directed users to carry out the same task in each of the three experimental arms. We asked clinicians about order navigation, layout, specific content, usability, and how the designs flowed in comparison to other common orders used. This structured interaction took place four times in the span of approximately 45 minutes. This amount of time was suitable for the evaluation and allowed each participant to share their opinions, both positive and negative, to refine the designs of each of the orders based on expert opinion.

Qualitative Analysis

Transcripts collected from the blood transfusion reduction UCD sessions were prepared by a professional transcriptionist. Transcripts were de-identified, time-stamped, and compared to recordings to correct any mistakes.

Importantly, we used a rapid analysis approach,[19] an efficient and flexible approach that is a good match for QI work in the health sciences due to the time it saves in analyzing qualitative data to arrive at an understanding of the data set. This technique allows rapid, iterative analysis of micro-interactions like the experience users have with a blood transfusion order. It is also characterized by the fluidity of data analysis, which occurs simultaneously with data collection, as well as a positivist and explanatory frame. The transcripts from the UCD think aloud sessions were the unit of analysis in this work, and the sample was 14 think aloud sessions.

In this approach, a data entry form is created for both the think aloud session and the semi-structured interview, giving each question or section a neutral domain name. Instead of the conventional coding of thematic qualitative analysis, researchers enter observations in real-time during the UCD exercise into a domain identified in the protocol and/or interview guide. These templates are shared amongst the research team so that consistency in observational findings can be confirmed. Findings from observations can be used to iteratively inform the UCD sessions. The observations, once there has been observational saturation, informed the recommendations for the design of the different blood transfusion orders.

Results

The order design with an interruptive alert (version C) was the most preferred version, with 8 out of a total of 14 users (57%) indicating it as "most preferred." Version A (general improvements) and version B (general improvements plus in-line noninterruptive nudges) were each rated as "most preferred" by 3 of 14 users (21.5%). User comments suggested that their preference was based on the design's effectiveness at warning them that they were ordering a nonindicated therapy. 100% of users noticed the new nudges in the order design that included an interruptive alert, compared with only 57% of users in the design in which the nudges were incorporated into the order as in-line text. Users reported the interruptive alert was better at getting the user's attention compared with in-line text, although they also commented that after repeated exposures to the interruptive alert, it might be a more cumbersome imposition on their work than the in-line text, especially once the expected behavior (e.g., only transfusing blood for a hemoglobin of $<$7.0 mg/dL) had been learned. They also expressed concern that in emergencies where blood is needed expediently, interruptive alerts add time to the workflow and might adversely affect patient care. Exemplar quotes are provided for versions A, B, and C in ►**Tables 2**, **3**, and **4**.

To make the in-line text more noticeable, many users agreed that larger font size in a more noticeable color such as red would add visibility (►**Fig. 3**). Also, while the in-line text was customized to their patient's hemoglobin value, most users (89%) did not realize this and thought the in-line text was a generic recommendation. Regarding the interruptive alert, users agreed that it would compromise their workflow less if it allowed users to change their order within the interruptive alert itself, rather than only making suggestions which they would then need to return to the order to correct (►**Fig. 4**).

The general improvements to the order, including the rearrangement of some order buttons, display of the last

Table 2 Exemplar quotes related to version A

Nudge to 1 unit
Okay. I think that will be okay. It will probably require some education because I don't want people to think they're transfusing two units when they click prepare for transfusion of two units and then have this default to one without them like catching it. So I think with some education that like, if you're transfusing more than one, you have to change it. That will be fine. But because it is auto selected and it doesn't make you select it, you might just skip right over that and not catch that. You're not transfusing as much as you thought you were (PID: BTR004). I mean, I think defaulting to one unit is a good idea because majority of the time, we're writing one unit at a time. (PID: BTR001).
We take care of trauma patients. We take care of transplant patients and it's not uncommon for us to give three, six units in a few hours at times. We prefer not to use massive transfusion protocol when we can especially in transplant patients with immunosuppression antibodies, things like that (PID: BTR006).
Well, certainly from our perspective, it is our routine and built into our order sets and everything to transfuse one unit, which is reasonable in most cases. And this is something you can change, I guess. But defaulting, I think you'll save blood because many times people will say, "Let's give two units," and that used to be our standard until we switched a while back. (PID: BTR014).

Table 3 Exemplar quotes related to Version B

Inline guidelines
Yeah. But in an ideal world, it would be like the previous encounter where it was embedded in the "transfuse". So then you're only filling it out once. (PID: BTR011) Well, I don't mind the text. I think this is good info, especially because we're at a teaching hospital and there's a lot of people who are sort of new in their careers, or they get flustered, or they don't know exactly what the guidelines are. So, I think this is helpful. And so in my mind, once I've seen this, I would probably scroll through because it's kind of redundant down here. And

Table 4 Exemplar quotes related to Version C

Interruptive alert guidelines
I mean, I think probably the interruptive alert would probably be the best for pointing out that you're ordering something that's not indicated. It's pretty easy to look past that, like, that help text, especially when if it's not in bright red. (PID BTR001) Prob, so an interruptive alert always makes me pause and at least think for a second. (PID: BTR008). I click the transfuse RBC, and I'm acknowledging the reason, and it's this one here. And I say, okay. But then I have to click it again. Is there a way to make it, so that it populates—whatever I say—because these are the same selections that I previously had to click. But is there any way to carry it over so that it populates into this box? (PID: BTR013)
I think ideally having both the prepare and transfuse, the interruptive alert having to click the indication twice was a little more cumbersome and slows things down. A lot of times when we need blood, we need it quickly. And so adding steps or significant areas or places to miss something like actually transfusing and then having to wait for the nurse to try to release it, the blood bank to call and say they don't have a transfuse order can be detrimental. (PID: BTR006). I click the transfuse RBC, and I'm acknowledging the reason, and it's this one here. And I say, okay. But then I have to click it again. Is there a way to make it so that it populates—whatever I say—because these are the same selections that I previously had to click. But is there any way to carry it over so that it populates into this box? (PID: BTR013)

active Type and Screen (a necessary test to obtain before a blood transfusion), and updated text regarding guideline-based transfusion recommendations, were universally endorsed.

Finally, on the initial pass through the new orders, multiple users missed needing to click the "Transfuse" order to complete the transfusion. When asked, users were not used to this change and expressed worry that it could be missed. For example, one user stated, "If I actually wanted to transfuse them and I was moving fast, I would not see (the transfuse order) …I would ignore it and it wouldn't be until half an hour down the road that somebody would tell me, hey, you don't have the order in for transfuse RBCs."

Discussion

Findings

Users provided valuable feedback on the design of new orders that we incorporated into the final versions for the subsequent randomized trial. End users have proven effective in providing insights on transfusion practices[20,21] which was demonstrated here as well. Specifically, users provided

comments contrasting the visual noticeableness of the interruptive and noninterruptive alerts, recommendations for fewer clicks and more intuitive design, requests to make selections pertinent to the patient data,[13] and finally, implications for missing critical components of the order that may lead to patient safety concerns. Users also provided feedback on their preference for different versions.

Critically important for the planned randomized trial was that we found a large discrepancy in the number of users who noticed the in-line text compared to those who noticed the interruptive alert. With this feedback, we adjusted the in-line text display and the interruptive text display (►Fig. 2) so that we could truly evaluate "interruption" and not "did you even see the words." This is a critical point for the future study of CDS systems. Our approach reinforced that first-pass UCD and usability testing are important to make sure that investigators are studying what they intend, in this case, the "interruptive" versus "noninterruptive" properties of the CDS system and are not confounded by differences in human factors engineering choices that may hamper the effectiveness of one design over the other.

Regarding making the orders more user-friendly and less burdensome, users recommended less text, making patient-specific data more visible, bolding recommended actions, reducing the number of clicks, and making the flow of actions more intuitive. We incorporated this feedback by moving the patient-specific lab data about the last resulted Hgb, bolding the recommendation to transfuse one unit of packed red blood cells at a time, and removing text (►Fig. 2). We made the flow of actions more intuitive particularly in the interruptive alert by changing the workflow. The result was that users could select the indication for transfusion directly in the alert removing the need to duplicate the indication in the transfusion order (►Fig. 3).

To respond to users' recommendations to make the orders more specific and relevant to the individual patient, across each of the arms of the subsequent trial, we made the indications for transfusion specific to the patient data. Specifically, this meant incorporating display logic such that if the patient had a last known hemoglobin level of 6.9 g/dL or less, the indications no longer are displayed, and users may proceed (►Fig. 2). This was done because one of the generally accepted blood transfusion indications is a hemoglobin level less than 7.0 g/dL. Thus, a patient with a hemoglobin level less than 7.0 g/dL already has an accepted indication so no other justification for the transfusion is needed. This is in line with the "nudge" methodology to make doing the right thing (transfusing for an accepted recommendation) easier.[16,22] One important notation here is that before receiving this feedback from users, this was not a design feature we considered or even knew was possible. Our users directed us to ask questions of the EHR platform that we would not have otherwise known were possible.

Lastly, we made a design choice to not precheck the transfusion order, only to prepare PRBC order. We hypothesized this would make users consider transfusing more carefully if a click was required. However, in the user-centered think aloud, we noticed multiple users did not notice the transfuse order needed to be clicked and thought they had successfully ordered the blood transfusion. This presents a potential patient safety issue if patients are not receiving blood transfusions when the clinicians intended. Thus, based on the results of these sessions we elected to precheck the transfuse order in the final versions, potentially reducing user error as has been done in several recent studies,[14,23] incorporated into the subsequent randomized trial.

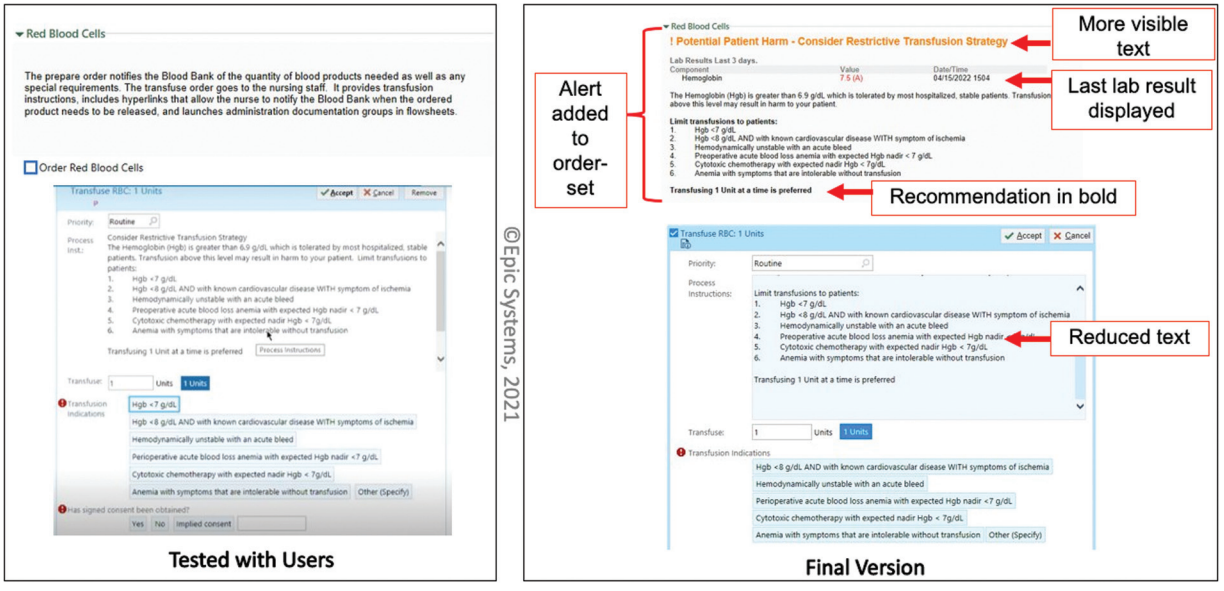

Fig. 3 Arm B—noninterruptive—before and after UCD testing. Screenshots of the before and after UCD testing with changes to noninterruptive alert detailed including adding it to the order, not just the transfuse order, making alert text larger and in orange to be more visible, adding last Hgb result, adding recommendation for 1U PRBC transfusion at a time in bed. We also reduced the amount of alert text in the Transfuse Order. Hgb, hemoglobin; UCD, user-centered design.

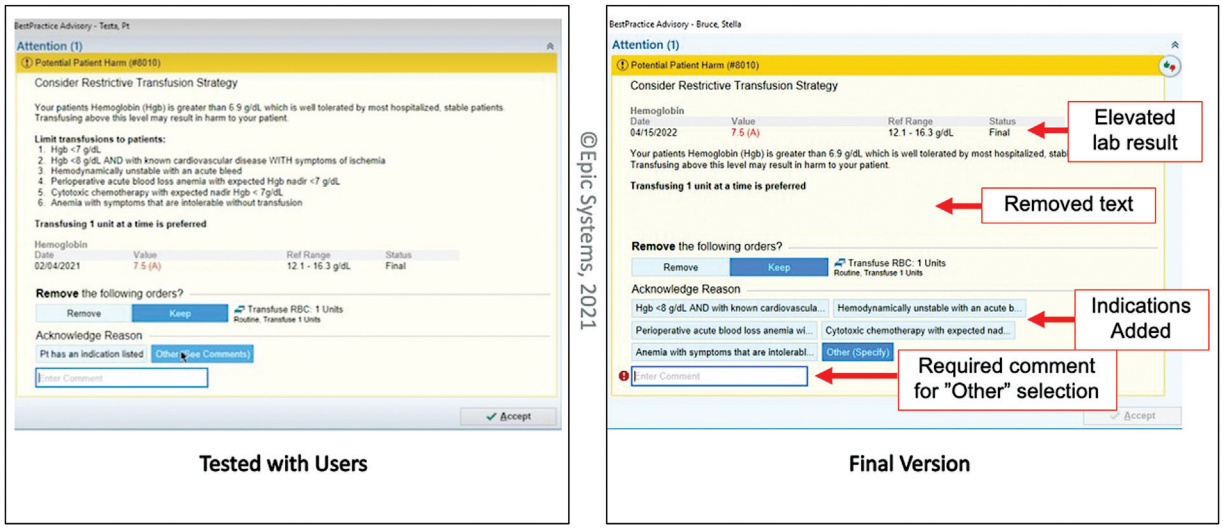

Fig. 4 Arm C—interruptive alert—before and after UCD testing. Screenshots of the before and after UCD testing with changes to the interruptive alert detailed including elevating lab result to higher in the view, removing indications text, adding indications as buttons, and requiring comment for "Other" selection. UCD, user-centered design.

Many of the above recommendations provided by users through these sessions reinforced our governing principle of using behavioral nudges, which is supported by previous work.[24–26] One of the strongest nudges, the display logic for the transfusion indications, came at the suggestion of the users who participated. Before these sessions, we did not consider this feature and did not know it was technically possible. At the urging of our users, we inquired with the EHR analysts and discovered display logic could be integrated into the orders.

Regarding the type of alerts, we were surprised that most users preferred the interruptive alert over the noninterruptive alerts, based on prior evidence that noninterruptive alerts are usually preferred by clinicians.[1] However, the users offered several caveats to this endorsement suggesting that the preference would wane with time, especially once the desired behavior was learned. Thus, the interruptive alert might progress from "helpful" to "annoying."

Without attention to human factors and design, the failure or success of any of the versions of the order might be confounded by the failure of the design, for example by failing to draw the user's attention to the most salient elements. We wanted the changes to our orders to be maximally visible to users in the clinical environment from the outset, ensuring the results of our randomized study were purely due to these changes and no other human factors. We, therefore, used a UCD approach and incorporated end-user insights and suggestions collected during a simulated clinical scenario within an EHR test environment to refine and optimize the order design before the implementation of the larger CDS study.

Limitations

Our study has several limitations to generalizability. It was only performed at one institution, it focused on only one CDS system for one clinical scenario, and most participants were advanced practice providers.

We had 14 participants, though 8 to 10 participants were found to be sufficient for usability testing.[27] While we sought to draw from a broad range of specialties that typically order blood transfusions, there is known variability in transfusion practice, and therefore possibly in order design preference, between subspecialties, not all of which were represented in our sample. This may also limit the generalizability of our results.

Subjects' responses may have been influenced by their awareness that they were in a usability study of a CDS tool so their responses to differences in design may be different in actual clinical practice. The results of our randomized trial of the different order versions will be gathered in a real-world clinical scenario and may illuminate this possible discrepancy. Finally, the clinical vignette, though written to be applicable across specialties, may not have been representative of all clinical scenarios participants may encounter. Further, the vignette instructed participants to transfuse against generally accepted guidelines which, though common in clinical practice, may have limited the "realness" of the scenario depending on the practice patterns and guideline adherence of the participants.

Conclusion

In a randomized study of different CDS designs for a QI project aimed at reducing inappropriate blood transfusions, our approach of implementing a think aloud UCD protocol to record stakeholder input informed our CDS interventions. This approach may make it easier to discriminate the effects of these interventions being "interruptive" and "noninterruptive" by potentially ensuring parity in human factors among the different versions of the intervention. We feel confident that by conducting UCD sessions, we added value to the subsequent randomized trial by producing end-user informed final versions of the displays. Future investigators should incorporate user-centered approaches to inform CDS clinical trials.

Clinical Relevance Statement

This study can be used as a guide for the design of EHR order templates to improve workflow, adherence to guidelines, or in preparation for a clinical trial. The frequency of order use and perceptions of usability are important human factor considerations. User-centered design of orders in the EHR can improve clinician satisfaction, reduce burnout, and improve the perception of EHR usefulness in clinical care.

Multiple Choice Questions

1. What version of the blood transfusion order screens incorporated nudge principles to steer user toward guideline concordant ordering?
   a. Prepare order.
   b. Transfuse order.
   c. Noninterruptive alert.
   d. Interruptive alert.
   e. All of the above.

   Correct Answer: The correct option is e. Each screen was improved based on behavioral economic nudges, such as limiting options or prepopulating fields.

2. What is the definition of a behavioral nudge?
   a. Restriction of choices such that only the desired options are available.
   b. Minor change in framing choice that predictively alters people's behavior.
   c. Written text that provides an explanation for each choice presented to users.
   d. Significant economic reimbursement for desired outcomes.

   Correct Answer: The correct answer is option b. A behavioral nudge is a minor change in framing choice that predictively alters people's behavior.

Human Subjects Protections

This project was reviewed and categorized as a quality improvement by the Colorado Multiple Institutional Review Board (COMIRB) and was therefore exempt from approval.

Conflict of Interest

None declared.

Acknowledgments

The authors would like to acknowledge the University of Colorado School of Medicine that made the Data Science to Patient Value (D2V) initiative and The NavLab possible. They also acknowledge UCHealth for allowing our team to access personnel who made this project possible.

References

1 Blecker S, Pandya R, Stork S, et al. Interruptive versus noninterruptive clinical decision support: usability study. JMIR Human Factors 2019;6(02):e12469
2 Göttgens I, Oertelt-Prigione S. The application of human-centered design approaches in health research and innovation: a narrative review of current practices. JMIR Mhealth Uhealth 2021;9(12): e28102
3 Brunner J, Chuang E, Goldzweig C, Cain CL, Sugar C, Yano EM. User-centered design to improve clinical decision support in primary care. Int J Med Inform 2017;104:56–64
4 Colman N, Saldana C, Craig K, et al. Simulation-based user-centered design: an approach to device development during COVID-19. Pediatr Qual Saf 2021;6(04):e427
5 Clinical Practice Guidelines From the AABB. Red Blood Cell Transfusion Thresholds and Storage | Cardiothoracic Surgery. JAMA. JAMA Network. Accessed June 24, 2022 at: https://jamanetwork.com/journals/jama/article-abstract/2569055
6 Rigal JC, Riche VP, Tching-Sin M, et al. Cost of red blood cell transfusion; evaluation in a French academic hospital. Transfus Clin Biol 2020;27(04):222–228
7 Accurate costs of blood transfusion: a microcosting of administering blood products in the United Kingdom National Health Service - Stokes - 2018 - Transfusion - Wiley Online Library. Accessed June 24, 2022 at: https://onlinelibrary.wiley.com/doi/full/10.1111/trf.14493
8 Activity-based costs of blood transfusions in surgical patients at four hospitals - Shander - 2010 - Transfusion - Wiley Online Library. Accessed June 24, 2022 at: https://onlinelibrary.wiley.com/doi/full/10.1111/j.1537-2995.2009.02518.x
9 Trentino KM, Farmer SL, Swain SG, et al. Increased hospital costs associated with red blood cell transfusion. Transfusion 2015;55 (05):1082–1089
10 Transfusion thresholds and other strategies for guiding allogeneic red blood cell transfusion - Carson, JL – 2016. Cochrane Library. Accessed June 24, 2022 at: https://www.cochranelibrary.com/cdsr/doi/10.1002/14651858.CD002042.pub4/full
11 Mueller MM, Van Remoortel H, Meybohm P, et al; ICC PBM Frankfurt 2018 Group. Patient blood management: recommendations from the 2018 Frankfurt Consensus Conference. JAMA 2019;321(10):983–997
12 Norgaard A, De Lichtenberg TH, Nielsen J, Johansson PI. Monitoring compliance with transfusion guidelines in hospital departments by electronic data capture. Blood Transfus 2014;12(04): 509–519
13 Ikoma S, Furukawa M, Busuttil A, et al. Optimizing inpatient blood utilization using real-time clinical decision support. Appl Clin Inform 2021;12(01):49–56
14 Orenstein EW, Boudreaux J, Rollins M, et al. Formative usability testing reduces severe blood product ordering errors. Appl Clin Inform 2019 Oct; 10(05):981–990
15 Yarahuan JW, Billet A, Hron JD. A quality improvement initiative to decrease platelet ordering errors and a proposed model for evaluating clinical decision support effectiveness. Appl Clin Inform 2019;10(03):505–512
16 Glasgow RE, Knoepke CE, Magid D, et al. The NUDGE trial pragmatic trial to enhance cardiovascular medication adherence: study protocol for a randomized controlled trial. Trials 2021;22 (01):528
17 Patton MQ. Qualitative Research and Evaluation Methods. 3rd ed. Thousand Oaks, CA: Sage; 2002
18 Lewis C. Using the" thinking-aloud" method in cognitive interface design. IBM TJ Watson Research Center. Published online 1982. Accessed July 19, 2021 at: https://dominoweb.draco.res.ibm.com/reports/RC9265.pdf
19 Taylor B, Henshall C, Kenyon S, Litchfield I, Greenfield S. Can rapid approaches to qualitative analysis deliver timely, valid findings to clinical leaders? A mixed methods study comparing rapid and thematic analysis. BMJ Open 2018;8(10):e019993
20 Staccini P, Joubert M, Quaranta JF, Fieschi D, Fieschi M. Integration of health care process analysis in the design of a clinical

information system: applying to the blood transfusion process. Proc AMIA Symp 2000:824–828
21 Dzik WH. New technology for transfusion safety. Br J Haematol 2007;136(02):181–190
22 Nagtegaal R, Tummers L, Noordegraaf M, Bekkers V. Nudging healthcare professionals towards evidence-based medicine: a systematic scoping review. JBPA 2019;2(02):
23 Orenstein EW, Rollins M, Jones J, et al. Influence of user-centered clinical decision support on pediatric blood product ordering errors. Blood Transfus 2022 (e-pub ahead of print). Doi: 10.2450/2022.0309-21
24 Rowe TA, Brown T, Lee JY, et al. Development and pilot testing of EHR-nudges to reduce overuse in older primary care patients. Arch Gerontol Geriatr 2022;104:104794
25 Halpern SD. Using default options and other nudges to improve critical care. Crit Care Med 2018;46(03):460–464
26 Vaughn VM, Linder JA. Thoughtless design of the electronic health record drives overuse, but purposeful design can nudge improved patient care. BMJ Qual Saf 2018;27(08):583–586
27 Kushniruk AW, Patel VL. Cognitive and usability engineering methods for the evaluation of clinical information systems. J Biomed Inform 2004;37(01):56–76