Designing IT to reduce drug dose error

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- "Human error" is always an opportunity to think of ways to design technologies to reduce error.
- Even "simple" technology is much more complex and error-inducing to use than we like to think.
- Designing appropriate technologies is the key to reducing patient harm.
- This article shows one way to combine the best of reliable, easy to use, low technology ideas (like paper) with high technology ideas (like touch screens) to reduce patient harm.

About one in ten hospital admissions suffer an incident as a result of human error. Calculation errors are estimated to cause 10% of preventable deaths in hospitals. It is tempting, but wrong, to automatically blame the hospital staff. Obviously, IT and medical devices with embedded computers ought to be able to help reduce calculation errors significantly.

Let's focus on a "simple," routine design problem, but typical of broader technology design issues in healthcare, and raising in a particularly clear way some of the issues and design challenges that face us. Things we take for granted in design have subtleties it is easy to miss, and if we miss these issues, we design suboptimal products.

Here is the sort of calculation some nurses do every day: in chemotherapy, a patient is to be given 5,250 mg fluorouracil at a concentration of 45.57 mg per mL over 4 days [1,2]. What is the rate in mL per hour needed to program the patient's infusion pump? In a typical hospital environment these numbers have to be picked out from a complex background of pharmaceutical data printed on a drug label; see figure 1. Poor information design makes the nurses' problem harder.

Most people would use a calculator for this sort of problem. Unfortunately using a calculator is often unreliable. If the person making the calculation (it will take a minimum of 22 key presses) makes any slip, they will just get the wrong answer, but the calculator won't notice [3]. Ironically we tend to believe calculators, which makes it harder to notice errors (after all, we are using the calculator because we didn't know the right answer to start with!).

It is obvious that such routine calculations are so demanding that anybody would be unlikely to be able to get them right day after day never making a slip; it's amazing so many skilled nurses do something so complex faultlessly all the time. If a patient is given an overdose and dies, then, should we blame the nurse who pressed the button, or blame the system that asks nurses to do something that no normal human can do reliably?

There are probably millions of problems that go unreported, thankfully because the patient came to no obvious harm (though they may have stayed in hospital a bit longer). Fundamentally, we are not supporting clinicians to detect and manage errors. Most devices have no idea what a nurse is trying to do.

It seems obvious that more sophisticated "smart" infusion pumps connected to electronic patient records should be developed.

Unfortunately, it isn't as simple as just being "smart." There are several projects that aim to "design out error" but this is misguided; error is still going to happen, and if we have designed out error — the nurse must still be to blame! A computerization in an American hospital [4] doubled fatality rates in a paediatric ward. One reason was that, effectively, every patient lost a clinician because they now had to work on a computer rather than be hands on.

"Computerizing" what hospitals are currently doing will no doubt make them more efficient, but it does not address the underlying problems. People are approaching the wrong computational problems; calculators, *Excel*, conventional IT, clouds, are only superficial help. It's glib to say it, but we'll just have adverse incidents faster, not fewer or less harmful.

In our calculation example, a simple solution would be to improve the way pharmacies tell nurses what to do. Already, the pharmacy has a computer printer. Why not use the printer to print something better designed for the nurse's task?

Let's have a thought-provoking digression. A nomogram is a simple way to do a prepared calculation on a sheet of paper. All it needs is to draw a straight line on the paper. Figure 3 shows a nomogram that the pharmacy could have printed for our calculation problem. It can be printed on waterproof paper to make it more reliable for a hospital environment. The nomogram necessarily uses the right formula for the calculation. The computer has seen to that.

The nurse can now do the calculation on paper, and another nurse can check it very easily — it's just a matter of checking the lines drawn are right, rather than lots of tricky calculations on a calculator are right. Now just program the infusion pump to give 1.2 mL per hour.

The paper record is a very powerful benefit. The record is not just of the result of the calculation, it is a visual record. As the nurse slips the nomogram into the patient record folder, there'll be other ones there. A glance will confirm whether the new nomogram works the same way

It's not surprising that nomograms are used quite widely in healthcare. They are ideal for conditions where professionals are under difficult working conditions, such as in emergency departments. Nomograms even work well after they have been dropped! Experiments reported by Dave Williams *et al* [5] show that nomograms (used for complex burns calculations) are more reliable than calculators and conventional pencil and paper calculations. They are faster than paper and a comparable speed to conventional handheld calculators. It's interesting that *task-appropriate* technology, even though old, can do a better job than some modern technology.

Challenges to Health IT culture

Nomograms are cheap, simple and effective; they would save lives. The only reason not to get too excited was well-put by Atul Gawande in his excellent book *The Checklist Manifesto* [6], where he writes about the WHO Surgical Checklist — another cheap bit of paper — that reduces morbidity and mortality in surgery. If something good is free, it's not priceless but seems worthless. There is no multinational able to make a profit out of just printing bits of paper. Nomograms are so archaic, what modern pharmacy would think it an improvement using them when they could be buying modern technology?

More positively, it is exciting to see new interactive nomograms available on the iPad [7], and it is easy to imagine them modified for use on next-generation of infusion pumps and other devices with touch screens. Integration with patient records would avoid transcription errors transferring numbers to the pump itself. Either the infusion pump could do the nomogram itself (perhaps in a more compact form factor, like a type of slide rule [7], with a cursor and moving scales), or a tablet computer could wirelessly connect to the pump, thus giving the user a larger format, mobile and more convenient display than a fixed pump can.

One could give the drug label a QR to code specify the right nomogram for the tablet to show. The QR code, in figure 2, will download the nomogram shown in figure 3; you've got all the benefits of paper (dependability, auditability, etc) *as well as* the benefits of IT (security, automatic checks, relation to patient records, etc).

Since each nomogram can be printed for a specific patient and dose, it can take account of patient weight, etc, it can do a "dose error reduction" range check. It shouldn't be possible to calculate an overdose. With the nomogram shown here, as the bag is known to be 130 mL, the total dose (i.e., dose in mg/concentration in mg per mL) physically *cannot* exceed 130 mL, and the nomogram scale can end at 130 mL.

One is led to wonder if such "dose error reduction" calculations can be made by the pharmacy, why not just print the correct answer (1.2 mL per hour) on the bag and not risk human error in its repeated calculation? Figure 2 gives a mocked-up example of an improved drug label.

Health IT Culture

Part of the issues in improving health IT is that the healthcare practices and cultures current IT supports are to a greater and lesser extent counter-productive to being automated. The culture needs re-examining. Figure 3 gives a simple example of how we could improve the information design of a drug label. Why was the original label so badly designed in the first place (it isn't like it was the first ever drug bag label printed; where is the evidence of best practice?), and that a nurse had to repeat a tricky calculation already done for them, but disguised by extraneous and confusing information?

It is often said the problem in healthcare is the culture. But it goes deeper; the techie culture that wants to solve problems with "off the shelf" computers, clouds and all, risks solving the wrong problems and leaving the deeper ones untouched. Analysing the tasks that are actually being done, then seeing how to improve them to align with what computers do best is important. Just computerizing what's going on is a recipe for disaster. It's a sort-of business re-engineering, but now we call it user centred design [8].

What we can hope for is that one day in the future, if we are lucky, we will have dependable computers properly integrated into a more effective healthcare system; and that these improvements will be evidence-based. In the meantime, who wants to put the research effort in to improving things when the hospitals themselves don't demand a better system, and when technophiles think it self-evident that computerization means progress? There is considerable evidence that ignoring user centred design (i.e., human factors) is a naive mistake [landauer], to say nothing of the legal requirement to follow human factors-informed international standards such as ISO 62366.

The real problem is, when an incident occurs, it is far too easy (and far cheaper) to blame the nurse who pressed "the wrong button" when things go wrong. The ease of ignoring root causes perpetuates the myths. We should instead be blaming the unnecessary complexity, the unnecessary design faults, and, underlying it, the way we are failing to address the broader picture. If — when — we do that, the long range impact will be a reduction in the number of unnecessary hospital deaths, a rate that currently exceeds the death rate on the road, and deserves all the deep attention it can get [9].

Further reading

[1] ISMP, Institute for Safe Medication Practices, *Fluorouracil Incident Root Cause Analysis*, http://www.ismp-canada.org, 2007.

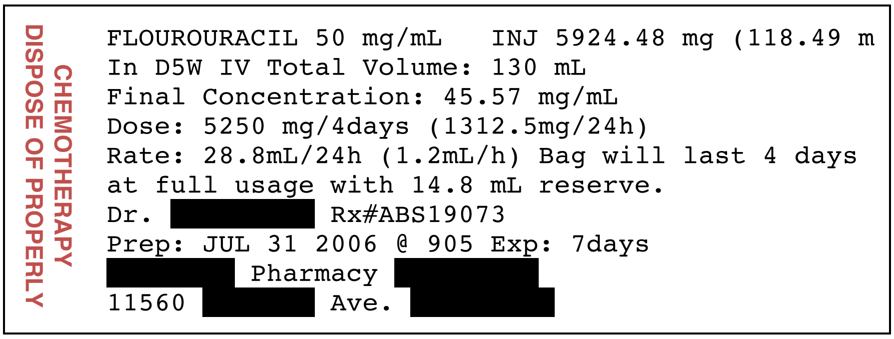
[2] H. Thimbleby, "Is IT a dangerous prescription?" *BCS Interfaces*, **84**:5–10, 2010.

[3] H. Thimbleby, "Ignorance of interaction programming is killing people," *ACM Interactions*, September+October:52–57, 2008.

[4] Y. Y. Han *et al*, "Unexpected Increased Mortality After Implementation of a Commercially Sold Computerized Physician Order Entry System," *Pediatrics*, **116**:1506-1512, 2005.

[5] A. Theron, O. Bodger & D. Williams, "Validation of a Nomogram to aid Fluid Resuscitation in Paediatric Burns," *European Journal of Anaesthesiology*, **29**(Supplement 50):154, 2012.

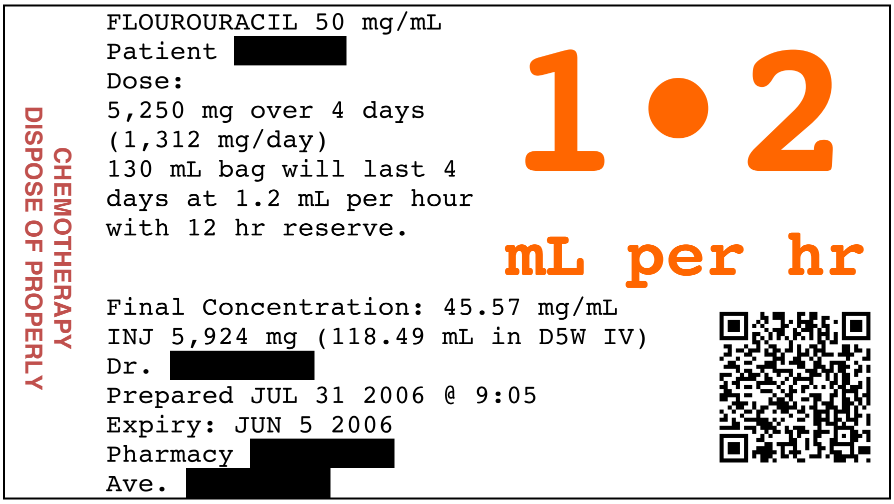
[6] A. Gawande, *The Checklist Manifesto*, Profile Books, 2010.
[7] NomoGraphics Oy, www.nomographics.com, 2011.
[8] H. Thimbleby, “Reaching to the stars with IT projects,” *Public Service Review: UK Science & Technology*, **5**:20–21, 2012.
[9] R. Koppel, S. M. Davidson, R. L. Wears & C. A. Sinsky, “Health Care Information Technology to the Rescue,” in R. Koppel & S. Gordon, eds. *First Do Less Harm: Confronting the Inconvenient Problems of Patient Safety*, 62–89, Cornell University Press, 2012.



CHEMOTHERAPY
DISPOSE OF PROPERLY

FLOUROURACIL 50 mg/mL   INJ 5924.48 mg (118.49 m
In D5W IV Total Volume: 130 mL
Final Concentration: 45.57 mg/mL
Dose: 5250 mg/4days (1312.5mg/24h)
Rate: 28.8mL/24h (1.2mL/h) Bag will last 4 days
at full usage with 14.8 mL reserve.
Dr. [redacted] Rx#ABS19073
Prep: JUL 31 2006 @ 905 Exp: 7days
[redacted] Pharmacy [redacted]
11560 [redacted] Ave. [redacted]

Figure 1. Reproduction of original drug bag label from [1]; the black regions were obscured in the ISMP root cause analysis to preserve anonymity. The ISMP report [1] criticizes the information design: there is far too much irrelevant information, and it is not presented to make the user's tasks (e.g., identifying the patient or calculating a rate in mL per hour) easy.



CHEMOTHERAPY
DISPOSE OF PROPERLY

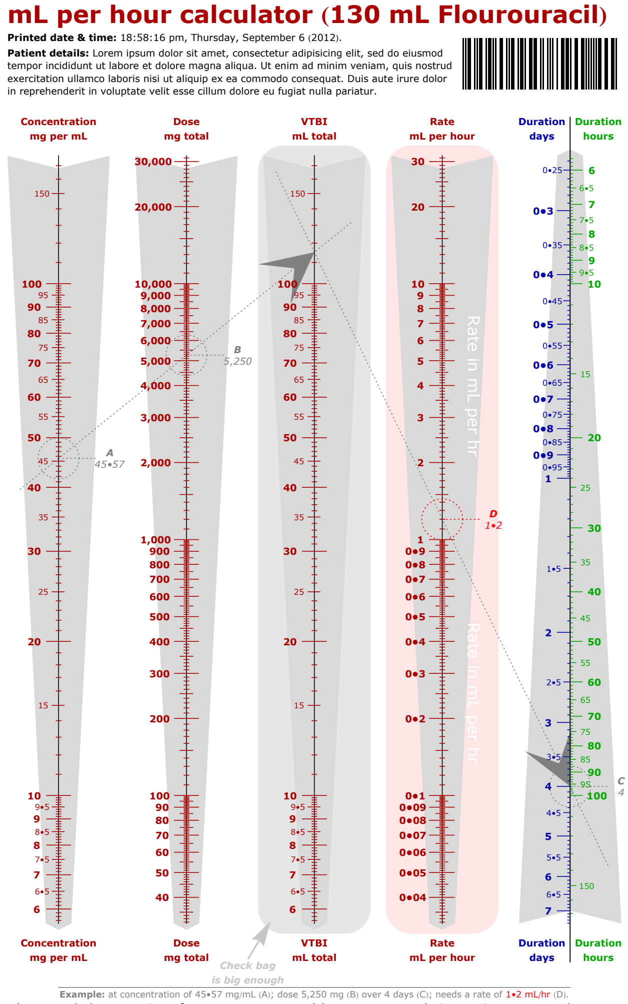
FLOUROURACIL 50 mg/mL
Patient [redacted]
Dose:
5,250 mg over 4 days
(1,312 mg/day)
130 mL bag will last 4
days at 1.2 mL per hour
with 12 hr reserve.

1•2
mL per hr

Final Concentration: 45.57 mg/mL
INJ 5,924 mg (118.49 mL in D5W IV)
Dr. [redacted]
Prepared JUL 31 2006 @ 9:05
Expiry: JUN 5 2006
Pharmacy [redacted]
Ave. [redacted]

Figure 2. Mock up of an improved drug bag label. As well as highlighting the required dose, we've also made the expiry, the times, etc easier to read; we've also removed the 28.8 mL per day dose as we know the infusion pump on the ward has to be programmed in mL per hour. Depending on the therapy, one might choose to make different information more prominent; here, we've made the dose rate in mL per hour prominent, as the incorrect calculation of this rate was a factor in a fluorouracil overdose fatality [8].

Figure 3. Dose calculation using a nomogram that can be used to work out the fluorouracil dose calculation in the article. The nomogram has patient details on it and a bar code to help need to check the patient, drugs, route and the nomogram are properly related.



The nomogram reproduced here is far too small to use this picture, but you can download a PDF of a proper-sized A4 version from http://www.harold.thimbleby.net/nomogram