Commentary

Reducing Post Analytical Error: Perspectives on New Formats for the Blood Sciences Pathology Report

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Abstract

Little has changed in the way we report pathology results from blood sciences over the last 50 years other than moving to electronic display from paper. In part, this is aspiration to preserve the format of a paper report in electronic format. It is also due to the limitations of electronic media to display the data. The advancement of web-based technologies and functionality of hand-held devices together with wireless and other technologies afford the opportunity to rethink data presentation with the aim of emphasising the message in the data, thereby modifying clinical behaviours and potentially reducing post-analytical error. This article takes the form of a commentary which explores new developments in the field of infographics and, together with examples, suggests some new approaches to communicating what is currently just data into information. The combination of graphics and a new approach to provocative interpretative commenting offers a powerful tool in improving pathology utilisation. An additional challenge is the requirement to consider how pathology reports may be issued directly to patients.

Author Note

The images and animations referred to in this commentary are best viewed on the authors website www.clinicalchem.co.uk , the online version of this article is in colour, and can be obtained through the publisher's website: http://www.aacb.asn.au.

Introduction

Good pathology utilisation depends on influencing the behaviours of our requestors. The format and content of the reports we issue are critical in respect of that aim. Infographics[1] have been around for centuries, but the rise of social media and other web-based means of information sharing mean that the tools to create them have become very sophisticated, widely available, inexpensive and in many cases free. We have not engaged with these developments in the way we report our results, and this is a missed opportunity for reducing post-analytical error. The potential for junior doctors to miss the meaning in respect of the interpretation of diagnostic data can result in patient injury due to failure of seeing patterns in the datasets of analytical values, and a failure of vigilance and clinical monitoring.[2,3] This is not surprising as the datasets that clinicians are required to review are becoming increasingly large and blood sciences results make a significant contribution to this. We have a high noise-to-signal ratio in the data we produce. This will inevitably lead to both over-testing as well as under-testing. Information overload can lead to failure of seeing significant patterns in the datasets of analytical values (false negatives) or perceiving patterns in the data that are not clinically significant and acting on them (false positives).

Studies in anaesthetics have demonstrated such failures of vigilance and clinical monitoring when reviewing results.[2,3]

There is a paucity of similar studies that have been applied to laboratory data.

This commentary introduces some ideas around how we can benefit through some of the advances in infographics in other fields and how they have the potential for being a powerful tool to facilitate good pathology utilisation, especially when combined with provocative interpretative commenting.

Provocative Interpretative Commenting

The addition of reporting/interpretative comments is not consistent across the pathology sub-specialities. For example in histopathology there is a highly-structured approach, with reports usually along the lines of:
- demographic and specific information
- gross description
- microscopic description and comment section
- intra-operative consultation
- final diagnosis
- general considerations.

In the other sub-specialities, a far less-structured approach is adopted. This has led to widespread variation in the way interpretative comments are added to results. These range from free text to predefined comments and often amended canned comments.

Theoretically, interpretative commenting is a very powerful tool for guiding management. In practice, there is still debate as to whether the addition of interpretative comments to laboratory reports can influence the management of patients. This was the subject of a paper by Eric Kilpatrick and Danielle Freedman in the *Annals of Clinical Biochemistry* in 2011.[4] They concluded by national survey:

- There was evidence that service users favour the provision of interpretative comments as well as appreciating additional testing.
- Over 75% of the recipients of report comments feel they influence patient management in the UK.
- There were examples of laboratory intervention which led to the avoidance of an acute admission or outpatient appointment.[5]
- general practitioners (GPs) in particular wanted more interpretative comments and found this an invaluable part of the 'laboratory service'.

In contrast, an Australasian study found a worryingly large proportion of comments could be inappropriate or, in some cases, potentially dangerous.[6]

What Constitutes a Good Comment?
A 'good comment' should:
- aim to answer the enquiring doctor's stated or implied question
- indicate the possible significance of the results
- suggest an appropriate response, for example, suggesting further investigation (not necessarily a laboratory test) or referral
- promote best practice
- promote clinical action
- avoid misinterpretation
- justify request denial
- reassure.

If we are to treat the request for a laboratory test as a referral, we should structure our interpretation along the same lines. We are, after all, giving an opinion on a patient.

There would be little need for the comments at all if a similar expertise among test requesters could always be guaranteed. Kilpatrick and Freedman comment that changes to undergraduate and junior doctor teaching in the UK have generally led to a reduction in the exposure of students to the pathology disciplines.[4] They suggest that this has resulted in doctors themselves identifying a training need in clinical biochemistry interpretation which, in turn, has led to calls

for this national teaching issue to be addressed.[7,8] Medics aside, there is also an increasing reliance on other healthcare staff to help in the management of patients, especially those with chronic illnesses. This combination of medical staff lacking confidence and other staff with little or no formal training in data interpretation means that clinical advice and interpretative comments from the laboratory are likely to become more necessary in the future.

What Constitutes a Good Report?
Given the diversity of the audience reviewing pathology data as well as level of training, to communicate effectively, the pathology report (data + interpretation) should be three things: complete, compelling, and controversial.

Our current means of being able to display only a subset of the complete record compromises completeness. This is especially true if the patient has a long complex medical history and the longitudinal pathology record comprises hundreds of result sets linked to multiple episodes of care stretching back over time. However, the pathology report can be complete in the context of the current clinical question being asked.

To grab a busy junior doctor's attention, the message we wish to send must also be compelling and stand apart from all other available data. How then do we reconcile this desire given the nature of the current limitations that govern how data is displayed? The incorporation of alphanumeric data into this scheme of display imposes an even greater problem when trying to integrate it into an overwhelmingly numerical format for the blood sciences.

Finally, controversy is always good. If the data we choose to display can elicit a response from our audience, we have achieved our aim.

Constructing an Engaging Narrative
In the UK, junior doctors (F1s, F2s) starting clinical placements are bombarded with information from a multiplicity of sources. In the author's hospital, the pathology component of the induction programme has been dropped in favour of more pressing information needs. In their daily practice they face constant distraction and the time available to comprehend the contents of a pathology report is severely limited. The challenge for us is to focus their attention to evoke the desired response in the following ways:
- promote clinical insight (the results strongly suggest a clinical condition)
- indicate an opportunity (promote a clinical action which may not have been considered)
- reduce uncertainty (narrow a differential diagnosis)
- reassure (confirm the utility of the current management plan).

Examples of a vocabulary for use in reports to achieve this aim include:

- consistent with
- eliminates
- confirms
- urgent referral required
- result confirmed using an alternative method.

Words to avoid

'Suggestive of…'. We are being asked to suggest, so these words are redundant.

Moving from Words to Graphics

The trick of presenting pathology data is that it can show trends and patterns lurking under the surface that the naked eye can't see, and others that exist on such a massive scale that we can't even fathom until they're put into numerical perspective. Ultimately, the goal of our narrative is to put those patterns into perspective. A way to achieve this is graphic representation linked to provocative interpretative commenting. We can even go one stage further so the infographic is the provocative comment.

The key to a successful graphical representation of data is that it is user friendly and immediately self-explanatory to the observer. An excellent example of what can be achieved is the urine colour chart reproduced from Boy Scouts of America (Figure 1).[9] The message is unambiguous and presented in a simple way that builds on basic knowledge and instinct. It needs no additional interpretation. Its effectiveness lies in its ability to communicate a message that translates into an action. It focuses on:

- clearly identifying a problem i.e. a disturbance in an ideal steady state or homeostasis, in this instance identifying two states; hydrated (blue = good)/dehydrated (red=bad)
- promoting an observation (urine colour) that best represents a disturbance in homeostasis and allowing an individual to be located (framed) within the problem space
- illustrating the temporal nature of the disturbance by showing it as a continuum
- promoting an action (drinking) to restore equilibrium.

In a reporting sense, it would be possible to mark the graphic with an individual's current urine colour density, thereby making it a reporting tool. However, despite being an excellent example of the power of an infographic, there are obvious technical limitations in the ability to use such a representation in current electronic pathology reporting technologies. Increasingly, reporting of results is becoming ever more web browser-based and there is an opportunity to take advantage of the software technologies that this medium supports for graphical display.
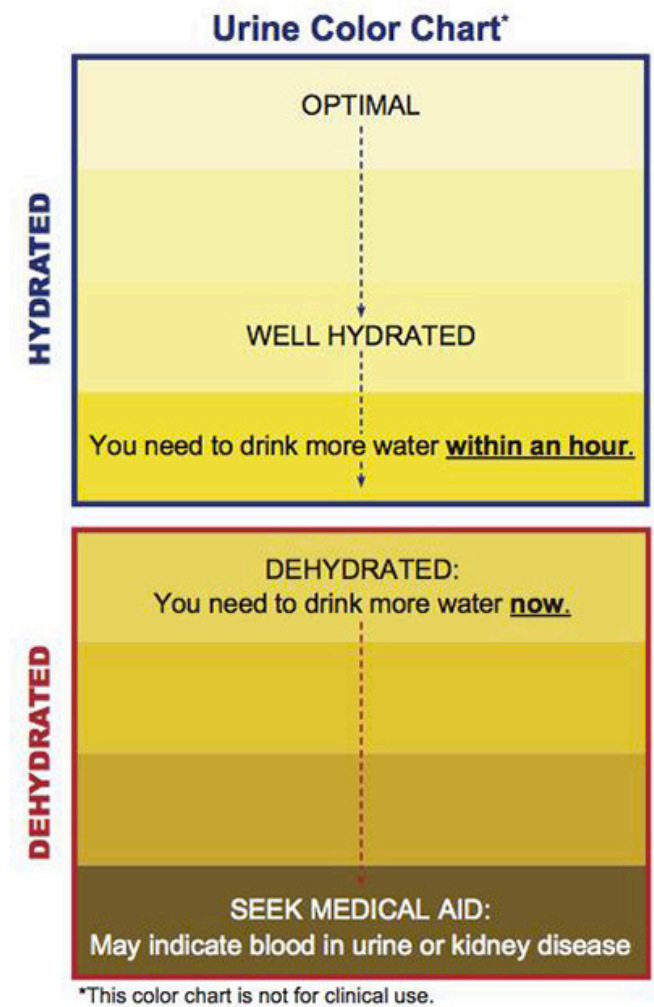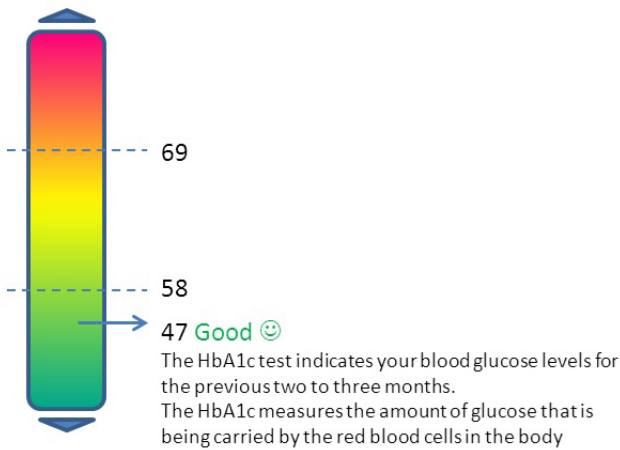

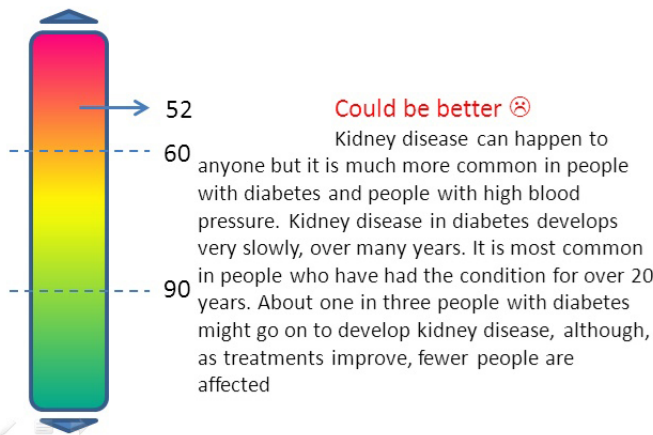**Figure 1**. Urine colour chart (courtesy of the Boy Scouts of America).

Targeting the Patient Audience

The main focus of this commentary is the communication of results to other healthcare professionals. However, there is an increasing desire for patients to have access to their own pathology reports. The challenge of designing reports destined directly for patient review without any medical intervention can only add to improvement in clarity and visual impact and is a welcome stimulus that will improve the quality of reports irrespective of the recipient. There are persuasive factors that will enable this to happen. In 2011 the UK government made a pledge that National Health Service patients would have full access to their summary care record by the end of parliament in 2015. This will presumably include access to the pathology record in due course.
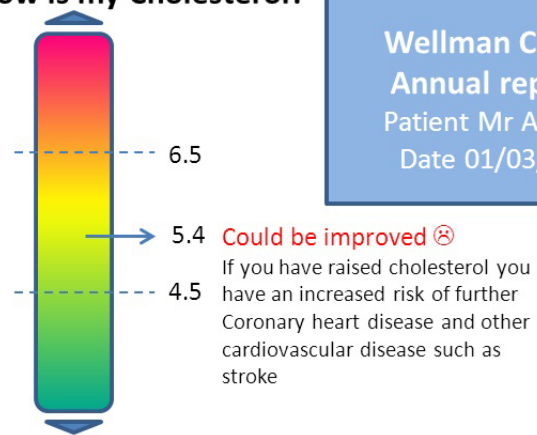
Diabetes test : How is my diabetes?

69

58

47 Good ☺
The HbA1c test indicates your blood glucose levels for
the previous two to three months.
The HbA1c measures the amount of glucose that is
being carried by the red blood cells in the body

GFR Renal test : How are my kidneys?

52

60

90

Could be better ☹
Kidney disease can happen to
anyone but it is much more common in people
with diabetes and people with high blood
pressure. Kidney disease in diabetes develops
very slowly, over many years. It is most common
in people who have had the condition for over 20
years. About one in three people with diabetes
might go on to develop kidney disease, although,
as treatments improve, fewer people are
affected

Cardiovascular Disease Test: How is my Cholesterol?

**Wellman Clinic
Annual report**
Patient Mr A Test
Date 01/03/14

6.5

5.4 **Could be improved** ☹
4.5   If you have raised cholesterol you
have an increased risk of further
Coronary heart disease and other
cardiovascular disease such as
stroke

Composite ranking for relative risks by GFR and albuminuria (KDIGO 2009)		Albuminuria stages, description and range (mg/g)		
		A1	A2	A3
		Optimal and high-normal	High	Very high and nephrotic
		<10	10–29	30–299 / 300–1999 / ≥2000
GFR stages, description and range (ml/min per 1.73 m²)	G1 High and optimal >105 / 90–104			
	G2 Mild 75–89 / 60–74			
	G3a Mild-moderate 45–59			
	G3b Moderate-severe 30–44			
	G4 Severe 15–29			
	G5 Kidney failure <15			

Your ACR = 12 ☹ (High normal)
Keep your blood sugars and blood pressure well
controlled to prevent any worsening of your kidneys.
Your Target Blood pressure is 130/80

Figure 2. An example of a patient-centric pathology report.

Patient access to their own pathology information is also a recurring theme in the recently published National Pathology Programme Digital First: Clinical Transformation through Pathology Innovation.[10] To quote from this document: 'Where changes such as patient access to the results of their blood tests have been introduced, the main benefit has been in a reduction in the number of visits required by patients – the use of this innovation by Kaiser Permanante is a widely recognised example.' Patients will most likely obtain their pathology results together with other elements of the summary care record directly from GP systems rather than from the pathology laboratory information management systems (LIMS), and clearly GPs must want to be involved in the presentation of such information.

There are also new commercial enterprises emerging, for example 'Patients Know Best' is a UK-based provider of patient-controlled medical records. Patients will have the ability to store and review their pathology record in such systems. There are also tools available for them to customise the data views.[11] The outputs from this and other healthcare portals will be web based and should be in a style familiar to the web browser community.

A feature article appeared in *Wired* magazine in 2010 which suggested some alternative structures for pathology reports specifically designed for patient review.[12] The style of reports chosen by the editor of that publication focused on providing a graphical answer to a specific clinical question. It is a challenge that links directly with some of the attributes of a good report previously mentioned, specifically:
• indicate the possible significance of the results
• suggest an appropriate response.
For example:
What are my chances of developing prostate cancer with a PSA result of ***?
What is my risk of developing coronary heart disease?

The availability of this style of report will inevitably influence the way pre-analytical requesting is undertaken. Order sets

designed for use with electronic order communication systems will increasingly be designed around the clinical question under consideration. This concept of problem-based requesting is also relevant to changing the behaviours of healthcare professionals and is discussed later in this commentary. Dr Darunee Whiting GP and Clinical Lead for Diagnostics Commissioning, Devon Northern Locality UK is currently investigating the possibility of generating such reports with GP system suppliers. An example of such a report I co-developed is shown in (Figure 2). The requirement here is the integration of physiological measurement (blood pressure) with the pathology data.

There are other opportunities afforded through using new browser technology plus new generation visualisation software which in many cases is free to use and therefore invites experimentation. For example a tag cloud is a visual representation for text data, typically used to depict keyword metadata on websites, or to visualise free-form text. Tags are usually single words, and the importance of each tag is shown with font size or colour. It would be relatively straightforward to incorporate this information in a dynamically generated personalised patient report.

This medium would work well when a single analyte is being reported. For example, compare the Vitamin D report in Figure 3 to its tag cloud equivalent (Figure 4). This visual technique works well in this context as we are framing the result of a single analyte into one risk category. Another benefit is that the cloud representation is able to show all of the possible categories the patient's result might fall into. This form of representation may well have some utility when considering reporting results directly to patients without medical intervention. It is but one very simple example of how web technology can be used. Web 3 technologies (also described as semantic or data driven) will allow data to be accessed from anywhere including cloud and smartphones, giving patients
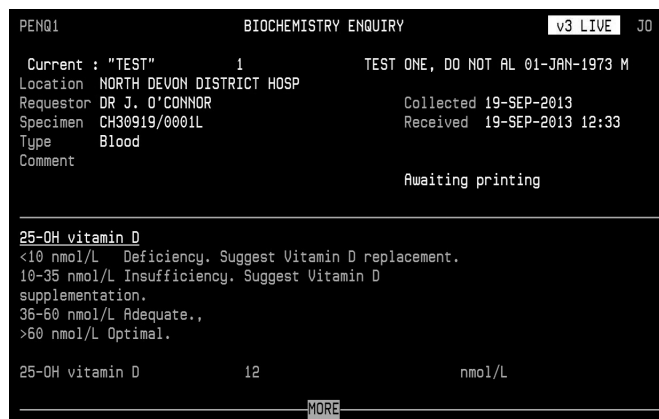

Figure 4. A Vitamin D report as a tag cloud.

enhanced accessibility to their clinical data. Our reports will need to be designed with these opportunities in mind.

Targeting the Healthcare Professional Audience
There are limitations to using these approaches when multivariate data needs to be displayed to healthcare professionals, especially junior doctors in an acute hospital environment. Pathology order sets tend to be much larger than those requested by primary care physicians where the typical Pareto of tests comprises eight orders.

Dealing with More Complex Data Sets
The problem we face with pathology data is one of 'data density' i.e. how much information can you work effectively into a small space. Generally, the more points of data you can clearly show the better, and this is a limitation of the display monitors currently in use, certainly in clinical environments. Increasing screen resolution is not a solution as again the viewer will be overwhelmed by data overload.

The result of this is that patterns in the data can be lost within an extended vertical list of data as well as trends not being obvious across time. In a traditional display cumulative view, typically the rows represent the analytes being measured and the columns contain the results of analysis arranged in chronological order with reference intervals occupying the far right of the display, this column being 'locked' such that it will always remain in view as the viewer scrolls the screen left and right.
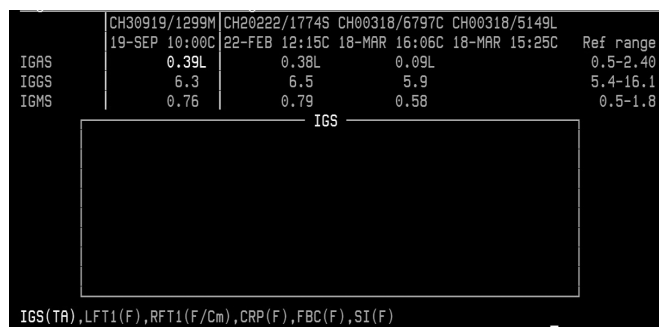

Figure 3. A standard Vitamin D report.

```
        CH30919/1299M CH20222/1774S CH00318/6797C CH00318/5149L
        19-SEP 10:00C 22-FEB 12:15C 18-MAR 16:06C 18-MAR 15:25C   Ref range
IGAS        0.39L         0.38L         0.09L                     0.5-2.40
IGGS        6.3           6.5           5.9                       5.4-16.1
IGMS        0.76          0.79          0.58                      0.5-1.8
                                   IGS



IGS(TA),LFT1(F),RFT1(F/Cm),CRP(F),FBC(F),SI(F)
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Figure 5. A standard cumulative display.

```
PENQ1                    BIOCHEMISTRY ENQUIRY              v3 LIVE   JO

 Current : "TEST"         1               TEST ONE, DO NOT AL 01-JAN-1973 M
Location  NORTH DEVON DISTRICT HOSP
Requestor DR J. O'CONNOR                        Collected 18-SEP-2013
Specimen  CH30918/0001N                         Received  18-SEP-2013 15:30
Type      Urine
Comment                                 The symbols on this report indicate:
                                        Sodium,clinically significant result compared to lower reference intervals.
                                        S Osmolality, result below reference interval.
                                        U Osmolality, highly significant elevation since last measurement.


Renal Function (General)
Sodium                      125   <<                  mmol/L      133 - 146
Random Urine Analysis
Sodium (random urine)        65                       mmol/L
Potassium (random urine)     12                       mmol/L
Osmolality (serum)
Osmolality (serum)          262   <                   mosmol/Kg   275 - 295
Osmolality (urine)
Osmolality (urine)          456   **                  mosmol/Kg
                             MORE
```

Figure 6. Standard pathology report utilising reporting system developed by Dr Bill Bartlett (http://www.biologicalvariation.com/index.html, Accessed 21/09/13).

Windows based displays allow such cumulative data to be displayed as line graphs but these can be confusing when a large number of analytes are displayed simultaneously and scaling can be problematic.

Analytes are generally grouped into logical organ profiles to promote recognition of derangements. Alert flags and colour coding of results are also liberally used. To highlight significant trends across time we use delta change tags against data items (Figure 5). The problem of over requesting leads to very large data sets and predictably very large spreadsheets, resulting in the person viewing the pathology record having to effectively navigate a fixed screen display window around a very large X,Y grid of data. Patterns and trends in the data will inevitably become lost because of the limitations of the view.

The next consideration is how significant change is reported. With current restrictions in electronic reporting it may be sufficient to use character-based formats. Relative and absolute change can be flagged using a delta change. LIMS systems allow local configuration of parameters specific to each analyte measured. This inevitably leads to a lack of harmonisation.

Dr Bill Bartlett, Consultant Biochemist, Ninewells Hospital, Dundee UK has developed a unique reporting format which encompasses both analytical and biological variation to calculate a clinically significant change. This approach adds significant value to the traditional delta change flagging approach. His system uses chevrons to indicate relativity to the reference intervals.
- < or > represents above or below reference interval.
- << or >> represents clinically significant result compared to upper or lower reference intervals.
- *= significant change since last measurement
- **= highly significant elevation since last measurement.

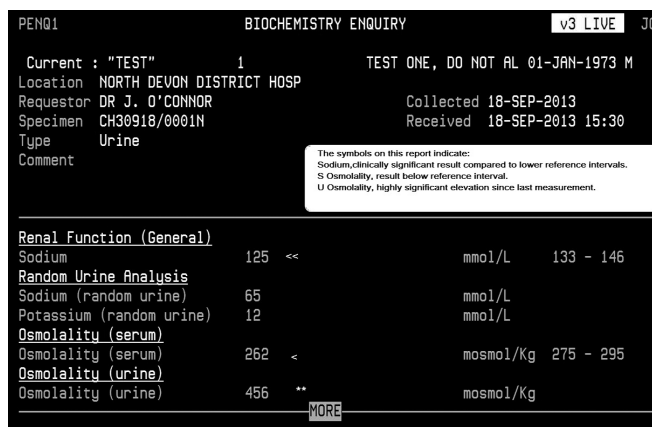This could be based on the 0.95 or 0.99 values for clinically significant change.

Figure 6 illustrates how this display might work in practice. By this means, he can identify both relativity to reference data and significance of change on the report using simple flags on a single report. Examples of this can be found on the biological variation website.[13]

Making the Complex Understandable

The main aim of using a graphic representation of data is to transform it into information which should stimulate the observer's own cognitive skills and promote an action. This has immense potential for redesigning the laboratory report to maximise its impact given the constraints on junior doctors' time. Graphic presentation of laboratory data can enable additional clarity, precision, and efficiency over a tabular report. It affords the opportunity of making the inaccessible, accessible thereby promoting a desirable response in the viewer.

Visual representation of laboratory data especially in the format of an Infographic should aspire to these ideals:
- **Accuracy**: represent laboratory data in a format whereby the meaning conveyed is subject to the lowest risk of mis-interpretation.
- Represent laboratory data with **optimal clarity**, promoting derangements in analytes most closely linked with the clinical question under consideration.
- **Accessible**: reveal the subtle shifts in analyte change, and emphasise clinically significant trends
- **Inform**: graphical representation of laboratory data can be utilised to teach the viewer about the relationship between the requested analyte and the clinical question under consideration. This has immense potential in respect of order sets for disease related profiles.
- **Add value**: the graphic should promote debate in the analytes requested in the context of the clinical question.

- **Optimised**: present the laboratory data in a way that's conducive to the medium in which it will primarily live (via the web, mobile, video, dashboard and so on)
- **Appealing**: use all the elements of a graphical display e.g. typography, colour, size and shape to help guide the meaning of a report to the requesting clinician.

Focusing on Structure

The structure of our laboratory reports shares international conformity. Reports are clear to those of us who work in and run laboratories. Concepts such as reference intervals, alert flags and delta changes are well understood and form part of the standard training programmes in pathology. It is challenging to consider how these concepts might be commuted to a graphic representation whilst still retaining the same meaning. To be informative the graphic must capture the underlying structure of our existing reports. However, if that is all that is achieved, we have missed a huge potential for promoting an action. One can think of our existing tabulated reports as relatively static entities; graphic representation of our data affords the possibility of making the content dynamic (Table).

Result datasets are already large and there is considerable variation in requesting patterns that cannot be explained by population differences or disease prevalence.[14] The use of graphic representations that portray which elements of laboratory data are relevant to the clinical question under investigation would also be another element in the measures we already employ to demand manage pathology requesting. The primary purpose of using graphic reports is to inform, but to control is another persuasive reason to implement them.

Selecting the Right Tools for the Job

Sparkline Theory and Practice

It is nearly 20 years since Powsner and Tufte published their sparkline representation of serial glucose estimations.[15] 'A sparkline is a small intense, simple, word-sized graphic with typographic resolution. Sparklines mean that graphics are no longer cartoonish special occasions with captions and boxes, but rather sparkline graphic can be everywhere a word or number can be: embedded in a sentence, table, headline, map, or spread sheet.'

Figure 7. A standard sparkline representation.

The large version of a sparkline (Figure 7) shows the fall in serum sodium over time. Context is provided by the grey shaded area which signifies normality. The power of sparklines is realised when they are aggregated to demonstrate trends in an order set.

The traditional report (Figure 8) shows the result profile resulting from a request for hyponatraemia ? cause order set. The sparkline representation might look something like Figure 9. Thus it is immediately obvious which analytes compose the order set, but more importantly, the temporal change in each individual analyte with the current value displayed to the right. What is not clear from this representation is the pathophysiology underpinning this pattern, in effect the differential diagnosis for this patient.

Bar Charts

Standard graphic charts include pie, bar, line and area. They can be used individually or in combination. Knowing what to use, when and how is complex as it will be determined not only by the underlying data structure but also on the desired outcome of presenting the graphic. The intended audience is a major factor in respect of laboratory results. A presentation designed for clinicians will concentrate on accuracy, elimination of bias with the ultimate aim of reducing post-analytical error

Table. Comparative features of tabular and graphic laboratory reports.

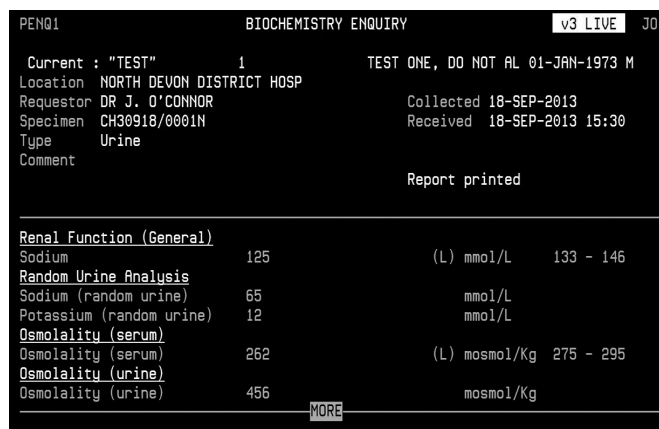| Tabular representation	Graphic representation
Data overload, important results are masked	Provides clarification
Skews interpretations. Patterns in the data are unclear	Aids comprehension
Reveals a trend	Highlights a trajectory
Obscures clinical significance	Highlights key findings

Figure 8. A standard report of hyponatraemia order set.

Figure 9. A composite sparkline report for hyponatraemia order set.

of interpretation and uncertainty. Additionally, clinicians will have enjoyed a considerable scientific component to their training and be comfortable with traditional charting forms. An infographic designed for a patient may concentrate on the communication of risk and emphasise strategies for risk reduction or avoidance. There are health literacy issues to be considered in the graphic modalities used.

There will inevitably be a tension in trading shape/visual appeal with function. This dynamic is the topic of an ongoing project being undertaken at the University of Michigan entitled 'Visualizing Health'. They have undertaken a survey study testing different designs with different audiences to establish the utility of the design approach.[16] It is an exceptional project and adds greatly to this field of knowledge.

The simplicity of the bar chart lends itself well to understanding by a wide audience both scientific and lay. Its prolific use in the popular media makes that format instantly recognisable, but more importantly, informative and intuitive. Bar charts allow data to be presented accurately, and their simplicity allows them to be used as a foundation for more complex customisations for displaying multidimensional data sets without losing the information contained within.

We should not be concerned about using a bar chart if that presents the data in its most accessible format. The question should be asked, 'Why is this better than a bar chart?' In blood sciences our stock in trade is visualising a single quantified measure over a single categorical dimension; for this there is rarely a better option. Likewise, time-based data is usually best displayed on a line chart, and scatterplots are often best for exploring correlations between two linear measures. There are good reasons these charts have been in continuous use since the 18th century. Bar charts are one of the best tools available for facilitating visual comparisons, leveraging our innate ability to precisely compare side-by-side lengths.
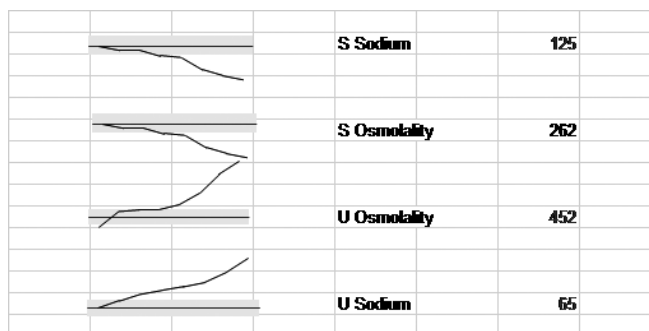
Innovative Bar Chart Use for Problem-Based Requesting

The challenge of reducing the size of the pathology datasets for meaningful presentation has already been discussed. The Royal College of Pathologists in their publication 'Clinical responses to the downturn' recommend a problem-based requesting approach (Figure 10).[17] This mode of requesting could very easily be incorporated into an order communication system, where additional information could be gathered at the time of request.

For example there could be an orderable profile in an order communication system catalogue called 'Hyponatraemia ? cause'. The basic blood sciences profile would consist of serum sodium, serum osmolality and urine sodium. Additional information regarding volaemic status adds context and meaning to the graphic display.

Using the single tabular view shown above (Figure 8), the results could be displayed in bar graph format (Figure 11). (I am indebted to Stephen Few at Perceptual edge for his contribution to this idea, personal communication.) The junior doctor would use this display to compare the patient's multivariate profile to that of those disease states that can contribute to low sodium. The six bar charts to the right of the patient's bar graph would be pre-set in the display software, akin to our current reference interval. It is very straightforward to see that the patient's dataset corresponds to the pattern of diarrhoea, skin loss or vomiting as the cause of hyponatraemia. The result of this is to enforce the pattern matching skills of junior staff and to demonstrate what the weightings of the component tests are in relation to the final diagnosis. It also shows them which tests are relevant and will aid demand management as a result.

By combining the sparkline representation with the bar chart below into a single report adds real value as a visual tool. This gives us a temporal plus categorical display of the patient status. But could these two representations be incorporated into a single infographic? Motion charts may be the solution!

Figure 10. Screen capture taken from The Royal College of Pathologists publication 'Clinical responses to the downturn'.[17]

Motion Charts

Motion charts allow one to visualise trends and patterns in data, showing several dimensions simultaneously over time. Recently Google have made the motion chart API freely available.[18] To appreciate the power and functionality of the motion charts for of visualisation, run the example from my web server at: http://www.clinicalchem.co.uk/lines3.html. To run this example, you will need to use Netscape or Chrome browser.

(i)   Change the label of the abscissa axis to 'Time'.
(ii) For best results select 'All' for analytes in the bottom right window.
(iii) Click 'Trails' on and click the play button to visualise.
(iv) In the default view the colour change of the traces indicates an analyte going out of reference interval (Figure 12).
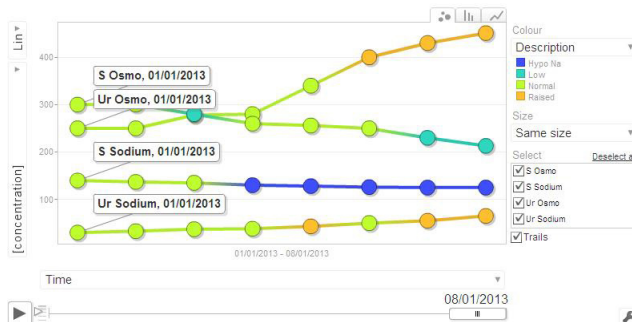
Figure 12. Screen capture of the motion chart for hyponatraemia showing ranges.

The real power of this tool comes by changing the view to 'Clinical' in the top right menu. This enables significant clinical events to be highlighted in relation to the dynamic change in parameters. For example, in Figure 13, we can see the change from euvolaemic state (green) to hypovolaemic because of D+V in blue. This Flash animation technique offers endless possibilities for pathology data display.
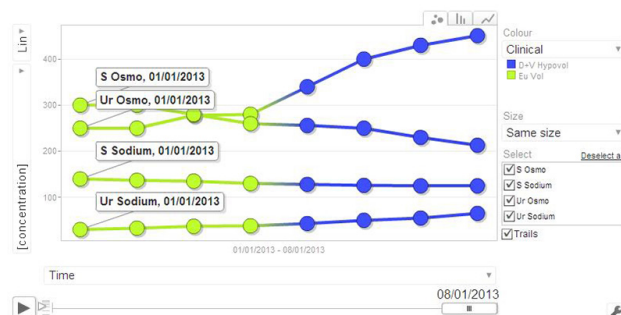

Figure 13. Screen capture of the motion chart for hyponatraemia showing clinical change.

Diagnostic Schema Maps

Human factor studies in non-medical domains have shown that graphical design of monitoring systems can improve detection, control and prediction of future states.[19-22] Human
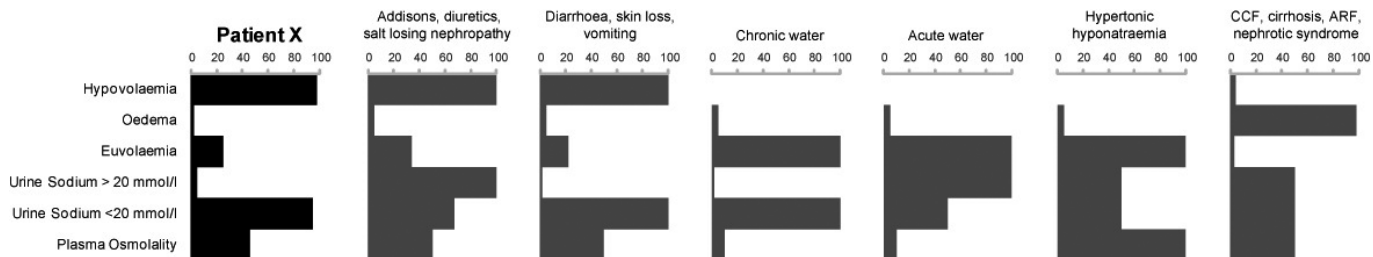

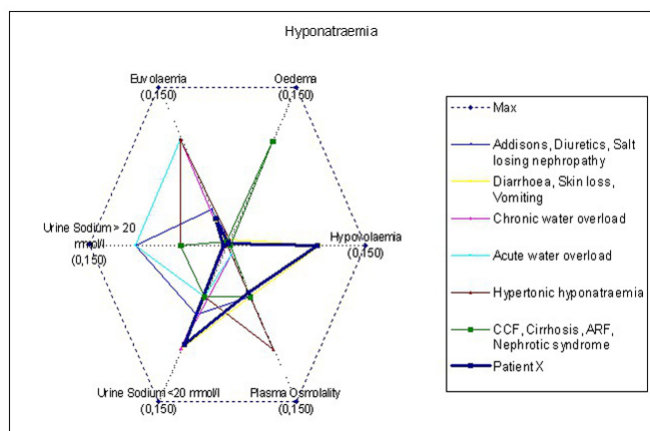**Figure 11**. Bar chart representation of the hyponatraemia diagnostic differential.

Figure 14. Configural display of hyponatraemia.

Figure 15. Diagnostic schema map category template.

factor design principles have led to the development of many types of medical graphical display. One approach termed the configural display has been shown to decrease diagnostic uncertainty when representing multidimensional data and in particular, datasets that change over time.[23,24]

An example of a configural display replicating the hyponatraemia example above is shown in Figure 14. This display looks somewhat complicated because all the condition states are represented in the same physical space and overlap each other; the bar chart works better in that context. However, the configural display metaphor can be taken one stage on to what I will henceforth describe as 'diagnostic schema maps'. This involves displaying test results in such a way as to allow relationships between them to emerge into a higher level relation; a more composite and general display of what the data means. The mapping of patient test results onto these displays allows a pattern or shape to be created from the low level data which is recognisable, has meaning and most importantly has the potential to represent temporal change.

The current view of laboratory data is a display form known as 'separable', where each variable is shown as a single output. Currently, we attempt integration or higher level relations to hopefully emerge by grouping results into profiles e.g. liver function tests, as an aid to interpretation.

Configural displays arrange low level data into a meaningful form which is greater than the sum of the parts and is based on principles of gestalt psychology. Separable display generally makes it easier to extract low level information and, although harder to integrate, does afford some benefits in test interpretation. In contrast, configural display makes it harder to extract low level information. The diagnostic schema maps concept preserves the separable view of analytes whilst still attaining a configurable view making the data easier to integrate.
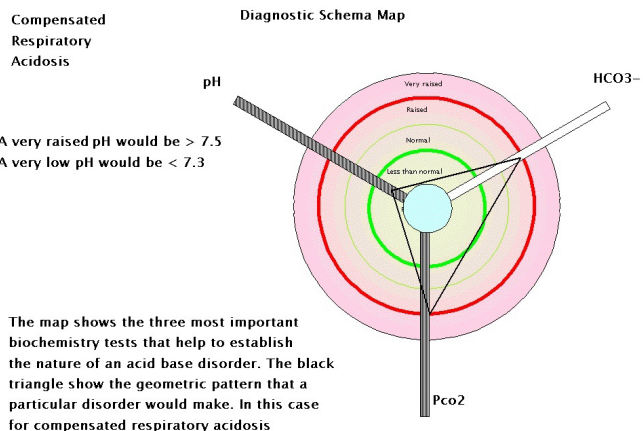
Diagnostic schema maps are polar style N polygon configural displays. They are typically an asymmetric geometric shape. The emergent property is the shape of this object. They rely on human pattern recognition and visual cognition to identify a match with a diagnostic category. The schema maps can be thought of as an abstraction hierarchy at the lowest level: it contains a graphic depicting range, and above this are plotted the analytes that form the profile in the context.

The example chosen to demonstrate the utility of the maps is acid base disturbances (Figure 15). Each axis shown on the map is a different analyte (variable), the measurement of which will assist in the identification of the acid base disorder. The analytes chosen give the best discrimination in relation to the set of possible outcomes. The maps were derived from the tabulated matrix of blood gas disorders represented in a standard biochemistry textbook.[25] The display also acts as an aid memoir to the requestor about the most appropriate tests to use in this situation. The concentric circles confer the abstraction of 'normality' to the mapped results.

There are important issues regarding the subjective descriptions of what is considered 'raised' or 'very raised'. Pragmatically, the 'raised' ring corresponds with the clinical alert level used to flag abnormal results on printed laboratory reports whereas 'very raised' corresponds with an action alert which would usually prompt contact with the requesting clinician.

The highest level of the abstraction hierarchy is the geometric shapes that relate to a diagnostic entity. Patient results can then be overlaid on the map as demonstrated in Figure 16. The yellow triangle reflects the patient's results which show no acid base disturbance. They can also be used to represent snapshots of test profiles to suggest a possible underlying disease process that can explain the patterns made by the individual analytes. Figure 17 shows eight diagnostic schema maps that describe a range of acid base disorders.
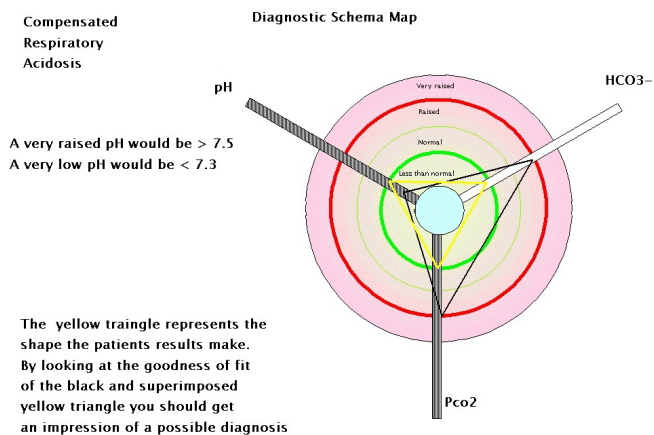
Figure 16. Diagnostic schema map category template with patient result overlay.

Figure 17. Diagnostic schema map (n) category template for acid base disorders.

To test the utility of diagnostic schema maps, a series of clinical cases involving acid base disturbance was chosen. The choice was deliberate as the interpretation of blood gases and pH remain complex because of the co-existence of different disturbances that often occur. A paper-based exercise was undertaken using a series of nine acid base clinical scenarios with associated blood gas analysis data with a questionnaire asking what the most likely acid base disturbance was. The exercise was then repeated with the same set of cases, but assisted by the associated diagnostic schema maps available. Third-year medical students (n = 24) were used to test the concept. There were a total of 216 correct possible responses. Unaided there were 184 correct responses (85%). Using the schema maps there were 205 correct responses (95%).

The main consideration in the construction of the diagnostic schema maps was to keep them as simple as possible. Complex and non-intuitive displays add additional cognitive workload to the user,[20-22,26,27] and from the perspective of the junior doctor reviewing hundreds of biochemistry panels daily this is an important consideration. This experiment demonstrated that a display design which incorporates knowledge gained from human factor research and cognitive design should be far more intuitive to use and reduce cognitive workload, and confirms the findings of other studies.[26,27] The approach overcomes the limitations of purely character-based data display, which do not communicate the diagnostic messages held in the datasets due to information overload. Diagnostic schema maps are designed to maximise the clinician's awareness of important patterns in the data that link directly with diagnostic dilemmas and are designed to be consistent with their clinical processes and mental models.

Operational Implementation

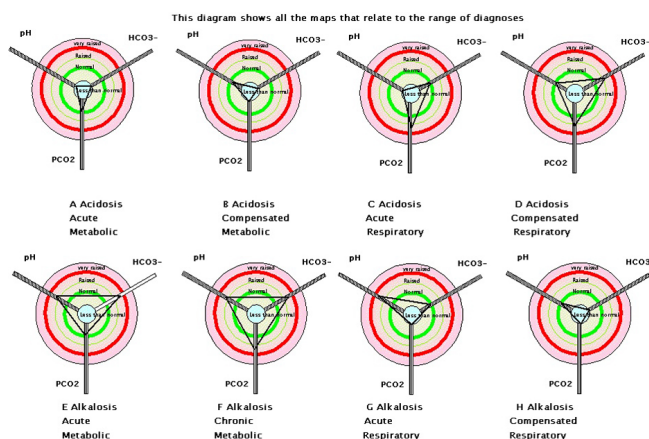All of the infographic images described in this article could be available as browser-based representations on ward-based clinical workstations using w3 and Java. Operationally they could be used in conjunction with an order requesting system. They would operate most effectively with previously-described problem-based requesting where panels of tests could be linked to a diagnostic question.

Clearly there are innumerate clinical scenarios that would require an equal number of diagnostic schema maps or preset bar chats. However the old adage 'common things occur frequently' is no more true than in medicine. It is also true that junior doctors have certain comprehension black spot areas. This has spawned many reference tomes containing algorithms to clarify these complex scenarios. Initially the infographics could be developed from these algorithms. However, the whole process would be incremental.

Dynamic Algorithms

Allowing junior doctors access to additional information whilst they are reviewing pathology results gives us the opportunity to get greater value from the report as well as both educating and promoting best practice. This is not a new idea at all. The majority of order communication systems that have a result review capacity allow for dynamic hyperlinking to any number of web-based decision support information sources. Using order set reporting can clearly make hyperlinking to a relevant web-based algorithm very simple.

Access to diagnostic algorithms can be very useful in this context: these can represent national best practice guidance or promote local protocols and procedures. A problem with these algorithms is that they can be very complex if the problem space in question requires a large number of stages to fully explore the problem space. Value stream mapping is a methodology gaining popularity in the UK for encouraging lean processes in the laboratory environment. It is a technique used to analyse and design the flow of materials

and information required to bring a product or service to a consumer. At Toyota, where the technique originated, it is known as 'material and information flow mapping'.[28] It can be applied to almost any value chain.

Take for example the value stream map from Dr Tom Lewis, Consultant Microbiologist at North Devon District Hospital, for women suffering dysuria (Figure 18). The map can be a little confusing as the problem space is large and suffers from being static and not containing additional information about local advice as to next actions. Using very simple-to-use and completely free mind mapping software Freemind, I have converted this static entity to something far more dynamic that allows decision support by representing the value stream such that not all the information is displayed at once. Rather, the user is able to click on the nodes to unfold the map in a logical stepwise manner such that it becomes a decision support tool. This can only really be appreciated by interacting with the map online at http://www.clinicalchem.co.uk/javafiles/freemindbrowser.html. (Note you will need to have Java loaded on to your local computer and it looks best in IE7 or Netscape.)

By building decision support tools in this style we can also emulate the concept of the diagnostic cascade, by reserving those relatively inexpensive tests first-line tests with good diagnostic discriminatory utility at the top of the cascade and reserving the confirmatory tests (expensive) at the bottom of the tree. Figure 19 shows the value stream mapping from Figure 18 fully expanded as an algorithm.

Discussion

In this commentary, I have tried to introduce some ideas around how infographics might be incorporated into an electronic report which could be used in an acute hospital environment, the primary care community and to patients themselves. They should be seen as a powerful tool in attempting to reduce post-analytical error. In his paper 'The detection and prevention of errors in laboratory medicine' Mario Plebani describes post-post-analytical error which comprises:[29]

- delayed/missed reaction to laboratory reporting
- incorrect interpretation
- inappropriate/inadequate follow-up plan
- failure to order appropriate consultation.

Together, these errors are reported as occurring with a relative frequency of 25–45.5%. In particular, he found that the incorrect interpretation of diagnostic or laboratory tests was found to be responsible for a high percentage of errors in the ambulatory setting as well as in emergency departments. The paper goes on to suggest a number of solutions to reduce error throughout the total testing process (TTP). Understandably
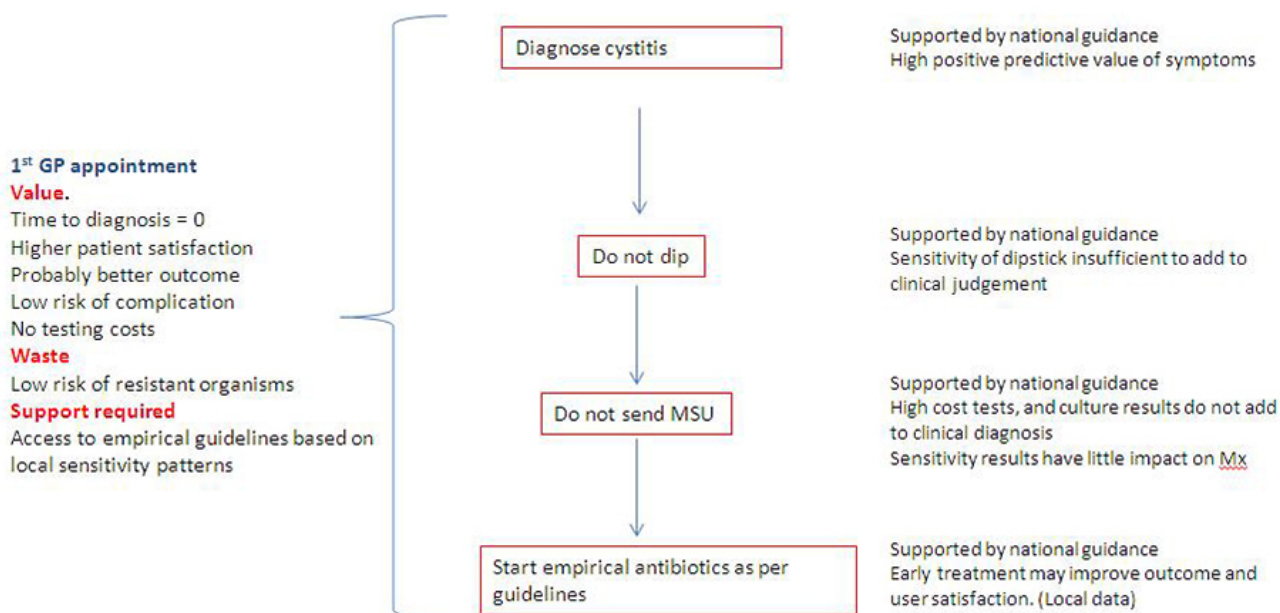

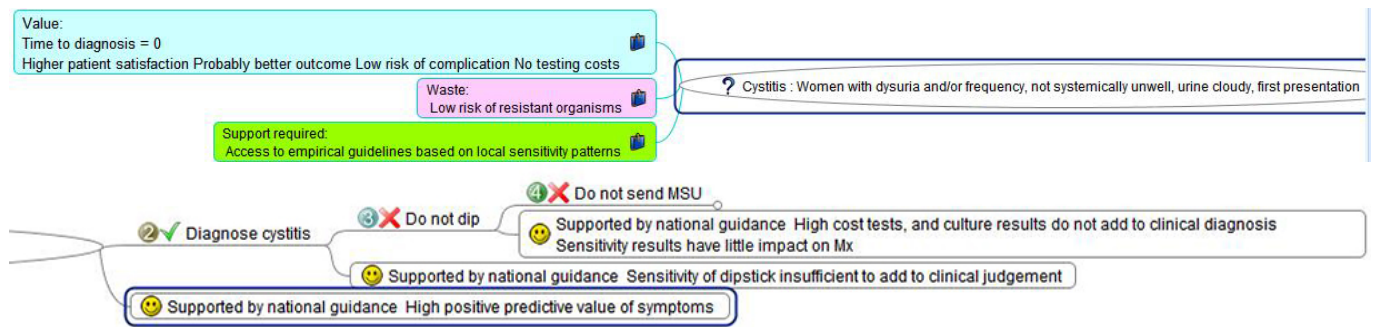Figure 18. Value stream map for dysuria.

Figure 19. Dynamic algorithm screenshot of dysuria.

the focus for addressing the problem is largely confined to the pre-, analytical and post-analytical phases of the TTP where the laboratory can still exercise a degree of control.

The post-post-analytical phase is the area where the greatest opportunity lies in rethinking how we report our results and where creative and intelligent presentation and display of our data has the greatest chance of changing clinical behaviours.

Infographics have the potential to:
• Indicate the possible significance of the results: reduce the risk to the patient of a missed or incorrect diagnosis; promote an action.
  The graphic format specifically designed for patients themselves is an example of where this type of report is most appropriate. There would be the requirement for patients to get additional information linked directly to recommendations in the report. An ideal repository for this would be a patient portal hosted on a GP practice website as an added value resource.

• Suggest an appropriate response, for example, suggesting further investigation, not necessarily a laboratory test, or referral: promote best practice; promote clinical action.
  Motion charts are an excellent means of linking a clinical event to a change in either a single or profile of parameters. The events that could easily be overlaid could include response to a medical intervention or change in therapy, emergence of a comorbidity or link to an established prognostic index.

• Educate junior medical staff by emphasising the importance of panels of analytical tests in respect of the underlying disease process: avoid misinterpretation; reassure; address the clinical question currently under consideration.
  Diagnostic schema maps have a distinct role in demonstrating the parameters that offer the best clinical utility in resolving a clinical question under consideration. They also have the ability to highlight how a patient's condition is changing from one predefined state to another

• Frame a laboratory investigation in the context of a patient pathway or clinical algorithm: reduce unnecessary testing; promote ordering the test with the greatest clinical utility. Dynamic algorithms allow the user to explore the use of pathology resources in the context of a clinical pathway with several outcomes without confusing them by showing the whole problem space in one view. The selective unfolding of the branches direct the user to order tests to resolve the most logical direction of travel through the algorithm.

Although data visualisation can yield meaningful insights and assist in problem solving for junior medical staff, it is important to remember that visualisation is a tool to aid analysis, not a substitute for analytical skill. It is also not a substitute for developing good diagnostic reasoning skills.

I would like to conclude by using a direct quote from *Beautiful Evidence* by Edward Tufte, widely regarded as the godfather of infographics.[30] 'Making an evidence presentation is a moral act as well as an intellectual activity. To maintain standards of quality, relevance, and integrity for evidence, consumers of presentations should insist that presenters be held intellectually and ethically responsible for what they show and tell. Thus consuming a presentation is also an intellectual and moral activity.'

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