Syringe labels seen through the eyes of the colour-deficient clinician

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Editor—In the hospital environment, a common use of colour is to distinguish between variants of a piece of equipment, for example blood tubes or sizes of cannula. There is little guidance on which colours should be used in constructing a safe and helpful colour code, and the choice is generally left to manufacturers. A rare exception to this is the labelling of syringes in critical care areas, for which clear and well thought out guidance is provided in the UK.[1] This guidance is backed by the Royal College of Anaesthetists, the Association of Anaesthetists of Great Britain and Ireland, the Royal College of Emergency Medicine, the Intensive Care Society, and the Faculty of Intensive Care Medicine. Similar guidelines are issued in the USA,[2] and there is also an ISO (International Organization for Standardization) standard.[3] For the individual with normal colour vision, there is little scope for confusion with such labels, as they use a mixture of colour, hatching, and reversal of font and background colour. There is evidence that syringe labelling systems can enhance the safe use of medication.[4]

Colour deficiency (the term now preferred to 'colour blindness') is common, and can be acquired (e.g. in glaucoma) or congenital. When congenital, it is almost always of the type characterised as 'red–green colour blindness', an X-linked condition. This affects around 8% of the male population[5] (and a far smaller proportion of females), and can be mild or severe. In the more severe form, the observer is dichromatic, relying on two rather than three cone classes owing to loss of middle- or long-wavelength-sensitive cones (conditions termed 'deuteranopia' and 'protanopia', respectively). About 2.5% of the male population are dichromatic.[5] Using mathematical transforms, it is possible to modify the appearance of a photograph so that the normal observer can see the image as it would appear to a dichromat.[6]

In the UK, as in most countries, no restrictions are placed on entry of the colour-deficient candidate into any branch of medicine. In India, several medical students were recently rejected from medical school on this basis, but the decision was overturned on appeal to the Indian Supreme Court.[7] Certain clinical distinctions are more difficult for the colour-deficient doctor,[8] but there has been no formal or useful guidance on how clinical colour codes should be constructed to accommodate the colour deficient. In 2015, there were 7422 NHS anaesthetic consultants, 68%[9] (5047) of whom were male. Unless self-selection occurs for particular specialities, there are likely around 288 anaesthetic consultants with milder forms of red–green deficiency, and 126 with the more severe form (dichromacy). The prevalence among other staff groups in the anaesthetic and critical care environments is also likely to reflect that of the general population.

One aspect of the accepted syringe labelling code is colour,[1] and specific Pantone® (Pantone LLC, Carlstadt, New Jersey, USA) colours are recommended for each class of drugs. All labels include the drug name and a space in which to write the concentration. Antagonists are marked with stripes, whereas suxamethonium and epinephrine have the font and background colour reversed to stand out. Fig. 1 shows labels for the major drug classes, and reconstructions of how these labels appear to the two common types of dichromat. Using a PhotoResearch 650 spectroradiometer (Photo Research, Syracuse, New York) with macro lens, we measured the chromaticities of a representative set of syringe labels and of the Pantone® colours suggested in the UK guidance[1] (uncoated Pantone® by Letraset™ swatch). In Fig. 2, the colours suggested in the most current guidelines[1,3] are plotted in the Commission Internationale de l'éclairage (CIE) (1931) chromaticity diagram, a standard two-dimensional space that allows all colours to be represented and also allows a direct prediction of which combinations of colours will be indistinguishable to the three classes of dichromat, that is combinations that fall on 'dichromatic confusion lines'.

The chromaticities are well separated in the CIE (1931) diagram, a result consistent with the impression from visual inspection that the colours are appropriate for the individual with normal colour vision. For the colour-deficient observer, however, there are shortcomings. For dichromats of the protan type, the chromaticities for vasopressors and opioids, and those for anti-emetics and neuromuscular blockers, fall on confusion lines. For dichromats of the deutan type, anti-emetics and anticholinergics fall on a confusion line. For dichromats of the tritan type, vasopressors and local anaesthetics fall on a confusion line. However, if we use not the printed labels but rather the colours shown in the UK and Ireland guidance (Fig. 1), then one interesting difference emerges: neuromuscular blockers are confusable with local anaesthetics, and not with anti-emetics.

We find that this discrepancy arises because of ambiguity in the guidance for the shade of red that should be used for neuromuscular blockers. The text of the UK and Ireland guidance specifies 'Pantone® 805 (fluorescent or warm red)', but 'warm red' is a distinct colour from Pantone® 805, whereas 'fluorescent red' does not exist in the Pantone® system (confirmed by discussion with Pantone LLC). The colour used on the printed labels available to us corresponds to 'sup warm red' (on our Pantone® swatch), which falls on a confusion line with anti-emetics, whereas Pantone® 805U falls on a confusion line with local anaesthetics. Thus, even by following the guidelines, different manufacturers could produce label sets that contain different confusions for the dichromatic doctor. By comparison, in the ISO system all suggested colour choices for neuromuscular blockers fall on a confusion line with anti-emetics, and never with local anaesthetics.

Where a colour code is widespread, it is likely to replace other means of visual identification (especially text) both in

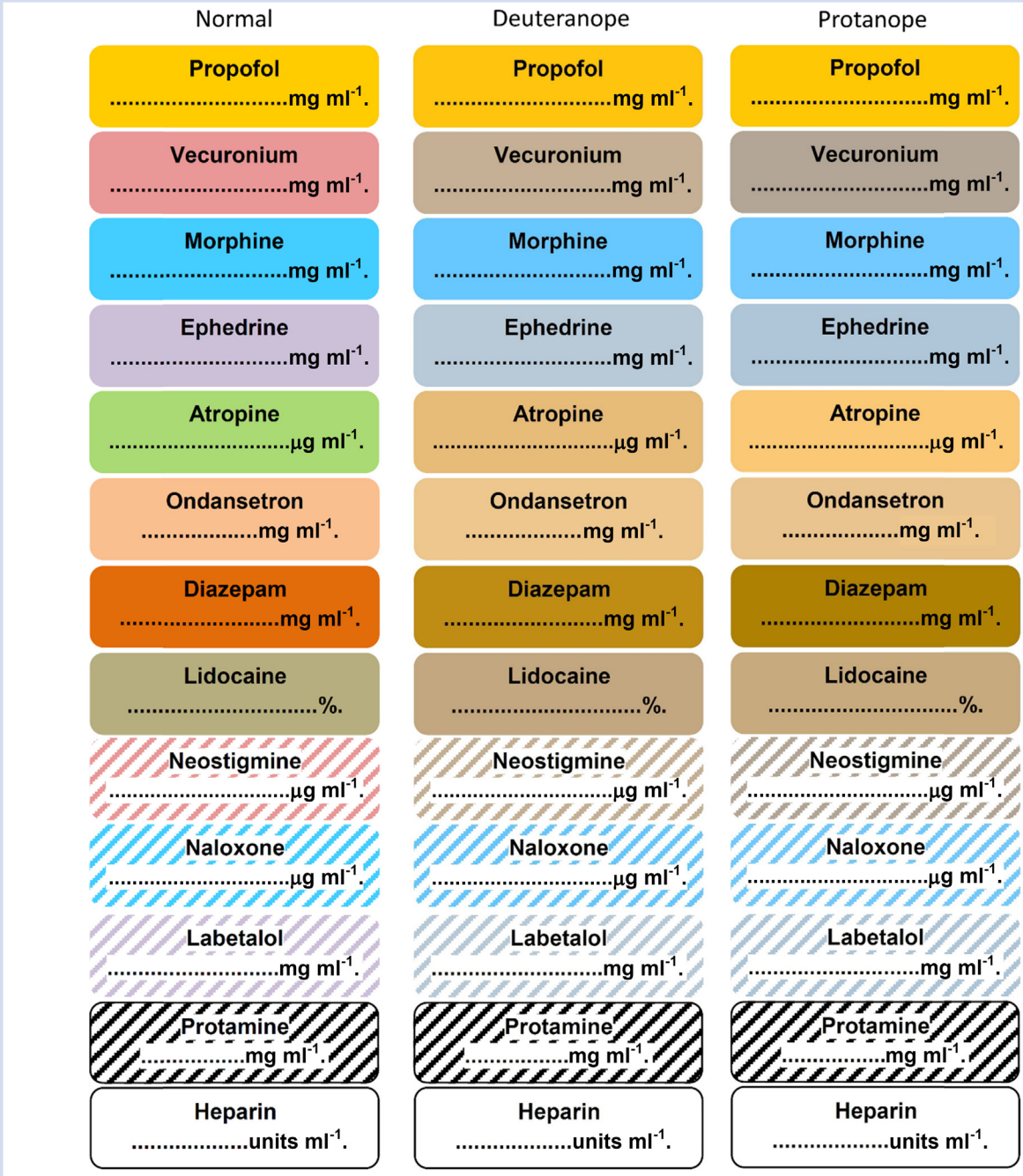

Fig 1. The left column shows the colour code recommended by, among others, the Royal College of Anaesthetists.[1] The centre column shows how these appear to deuteranopes (the more common group of dichromats), and the right column is the equivalent for protanopes. The pink label of vecuronium (used for all neuromuscular blocking agents) loses its colour when transformed for the dichromat, coming to closely resemble the grey of the lidocaine label (used for all local anaesthetics). Similarly, the green and pink hues of anticholinergic agents (atropine) and anti-emetics (ondansetron), respectively, lose their colour to become similar intermediate beiges. Transformations were created using software[11] based on established methodology.[6]

communication between team members (e.g. 'insert a grey cannula'), and for the individual when searching for a particular item. Colour coding is particularly useful when speed is of the essence, as it often is in the critical care and anaesthetic environments. The accepted guidance[1] for syringe labels will encourage reliance on the suggested colour code. Certain colours used in this code will be confusable for around 400 consultant anaesthetists (and many more trainees and allied health professionals) in the UK (Figs 1 and 2). Some of these clinical staff will be alert to their colour deficiency, but many may be completely unaware of it.[10] This raises the possibility of drug errors leading to patient harm either by accidental

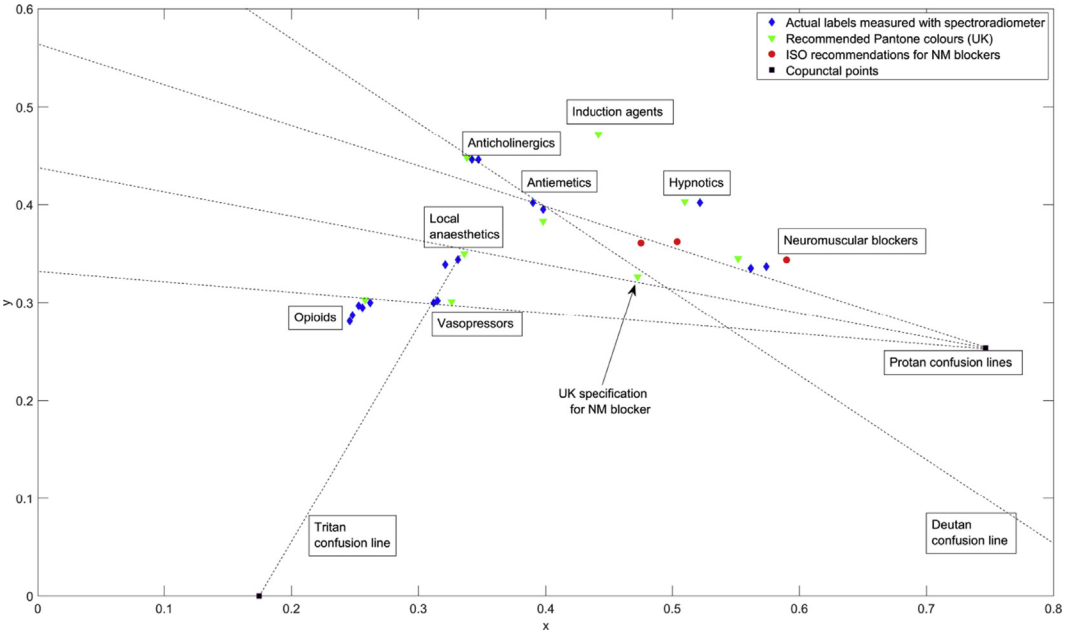

Fig 2. CIE 1931 colour space showing chromaticities of labels recorded by spectroradiometry (diamonds), colours recommended by the UK guidance (triangles), and colours recommended by ISO standard. Any pair of chromaticities lying on a line that passes through a co-punctal point are potentially confusable. The deutan co-punctal point is out of the bounds of this plot at x=1.4, y=−0.4. Confusion lines are illustrated for chromaticity pairs described in the text. ISO, International Organization for Standardization.

administration of an inappropriate agent or by failure to administer the correct agent.

Recommended labelling systems are excellent for clinicians with normal colour vision, and its adoption has been an improvement on the pre-existing situation. But should it be modified so as not to disadvantage colour-deficient clinicians?[12] Should, for example, a symbolic form cue (such as a wavy horizontal line) be added to the labels for neuromuscular blockers? There is an obvious danger of prompting a paradoxical increase in errors by changing a code that is already widely established. Moreover, there is no empirical evidence that errors are in fact more frequent among colour-deficient staff, whether experienced or inexperienced. We therefore confine ourselves to recording which pairs of labels are confusable by colour-deficient observers—and to drawing attention to the ambiguity in the published specification of the colour code for neuromuscular blockers. We hope that awareness of the potential for confusions in clinical colour codes might benefit future colour code design, and benefit patient safety.

Declaration of interest

The authors declare that they have no conflicts of interest.

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Monitoring transpulmonary pressure during anaesthesia using the PEEP-step method

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Editor—We appreciate the positive editorial,[1] comments,[2] and condensed description of our method of determining transpulmonary pressure without using oesophageal pressure, the PEEP-step method.[3] However, several issues need clarification.

The two key questions concerning PEEP are: (1) What factors determine the increase in end-expiratory lung volume (ΔEELV) after a change in PEEP? (2) Does a PEEP increase result in recruitment, that is, opening of closed alveoli, further inflation of already open alveoli, or both? In studies on patients with healthy lungs, and with moderate or severe acute respiratory distress syndrome (ARDS),[4] and with pulmonary and extrapulmonary ARDS,[5] where 5 cm H_2O-PEEP steps from 0 to 15 cm H_2O were performed, and in a study on mixed ARDS patients with PEEP steps from 5 to 40 cm H_2O,[6] we found that measured ΔEELV correlated along the line of identity with ΔEELV calculated as ΔPEEP times lung compliance (r^2=0.98).[7] We prospectively investigated the determinants of ΔEELV in pigs[8] and in patients with acute lung injury (ALI) or with healthy lungs[3,9] based on *tidal variation* in oesophageal pressure, and not on changes in absolute oesophageal pressure, which is questioned.[10] Pooled raw data showed a correlation between measured ΔEELV, and ΔEELV calculated as ΔPEEP times lung compliance correlated along the line of identity (r^2=0.90). Thus, ΔEELV is determined by the size of the PEEP step and elastic properties of the lung as ΔEELV=ΔPEEP×CL. If the equation is rearranged, it is obvious that lung compliance is equal to the change in end-expiratory lung volume divided by the change in PEEP, CL=ΔEELV/ΔPEEP.

Consequently, if ΔEELV is measured, lung compliance can be determined and transpulmonary pressure calculated without oesophageal pressure in patients with healthy lungs, and in patients with severe ARDS.

Grieco and colleagues[2,11] invoke the Dellamonica method for quantification of recruitment[12] against the PEEP-step method. In the original Dellamonica study, patients were divided into high recruiter or low recruiter groups. High recruiters had significantly higher respiratory system compliance compared with low recruiters, indicating that the Dellamonica method results in higher recruited volume with better lung condition. We compared the Dellamonica method in ARDS patients and patients with healthy lungs,[13] which also paradoxically showed that recruited volume was twice as high in patients with healthy lungs with little or no collapse[14] as in ARDS patients with abundant collapse. In patients with healthy lungs, electric impedance tomography (EIT) showed that both total ΔEELV and recruited volume according to Dellamonica emanated mainly from non-dependent lung regions. In an EIT study in ARDS patients, it was shown that the increase in compliance emanated in non-dependent lung regions and not from the most dependent regions as would be expected if PEEP inflation caused opening of previously collapsed alveoli.[15] These findings were recently confirmed by Chiumello and colleagues[16] in a CT scan study, in which they found 'that recruitment measured by the P–V curve method[17] (≈Dellamonica method)[12] was *proportional* to the amount of well-inflated lung, as is also suggested by gas distribution at higher PEEP in already well-aerated compartments'. However, in a similar CT scan study on ARDS patients, a decrease in non-aerated lung tissue by around 10% of ΔEELV was seen when PEEP was increased from ZEEP to 15 cm H_2O.[18] This indicates that a limited part of ΔEELV is a result of true recruitment, that is, conversion of non-aerated lung to poorly aerated lung tissue in dependent lung regions, whereas the main portion of ΔEELV is a result of further inflation of already poorly or well aerated lung above collapsed lung tissue.[19] This could be an indication that the PEEP-step method does not include very dependent lung regions, as both pleural and transpulmonary pressure are regional phenomena, varying in gravitational direction as described.[20] However, this is a problem associated only with transpulmonary driving pressure (ΔPL) determined by tidal oesophageal pressure variation (ΔPES), as ΔPES is mainly