Intravenous therapy: Drug calculations and medication issues

This is the second article in a series of three concerned with the delivery of effective intravenous (IV) therapy to the neonate and young child. The remit of this paper is to illustrate the different facets of drug calculations, to explore the occurrence of common medication errors and briefly describe factors that influence the incidence of adverse drug events.

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Key points

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1. Zero tolerance in medication errors is unlikely to be achievable. However, this should not prevent the implementation of strategies to minimise occurrences.
2. Neonatal and paediatric nurses who are not thoroughly familiar with all aspects of drug administration and the prescribed drug are putting not only their patients at risk, but also their professional practice.
3. Without accurate and timely reporting systems and the use of clinical governance and risk management strategies, medication errors will continue to occur at their present rates.
4. All staff must be particularly vigilant when using unlicensed and 'off-label' drugs for neonatal and paediatric patients.

Neonatal and paediatric nurses must be confident and competent in their ability to calculate drug dosages. The possibility for error is greater in the infant or child so extra care must be taken when administering medications[1,2]. There is a plethora of literature on medication errors and several that focus entirely on drug calculations[3-8].

In the following section the main influencing factors and the principles of drug calculation will be reviewed.

Drug calculations

The standard formula for drug calculations where volume is required for neonates and children is as follows:

$$\frac{\textit{Prescribed dose (what you want)}}{\textit{Dose of drug available (what you've got)}} \times \textit{Vol of drug (what it's in)}$$

As with any calculation, it is imperative that along with the numerical symbols the units of measurement are included. This will minimise the possibility of error due to a necessary conversion not being undertaken. The main factors to be taken into account are explored briefly below.

Infant/child weight

If the weight of the infant or child needs to be converted from grams (g) to kilograms (kg) then it will have to be divided by 1000 to give a figure that includes decimal places. This is unavoidable in order to work out a drug dosage correctly. Where a decimal point is required, remember to use a leading zero before the point, so that it is clear to colleagues where the decimal point is[2]. See **BOX 1** for a worked example.

Weights of children should be expressed in kilograms. If a weight in pounds is mistakenly recorded as kilograms then a 2.2 fold dosing error can result[2].

Unit of weight	Equivalent
1 kilogram (kg)	1000 grams
1 gram (g)	1000 milligrams
1 milligram (mg)	1000 micrograms
1 microgram (mcg or µg[a])	1000 nanograms
1 nanogram (ng[b])	

[a,b] While these abbreviations have been shown for consistency within the table, please remember that abbreviations for micrograms and nanograms should not be used in practice due to ease of confusion between them.

TABLE 1 Metric weights commonly used in neonatology and paediatrics.

To convert higher units to lower units multiply by 1000	Example
kg to g	5 kg = 5000 g
g to mg	1 g = 1000 mg
mg to mcg/µg	7 mg = 7000 mcg
mcg to ng	5 mcg = 5000 ng
To convert lower units to higher units divide by 1000	**Example**
ng to mcg	900 ng = 0.9 mcg
mcg to mg	100 mcg = 0.1 mg
mg to g	300 mg = 0.3 g
g to kg	10 g = 0.01 kg

TABLE 2 Commonly used conversions.

Drug weight

The most commonly used units of drug weight within the neonatal/paediatric environment are milligrams and micrograms, although grams and kilograms will also be encountered within drug calculations. The ability to convert from one measure of weight to another is imperative. **TABLE 1** provides the different units with their common abbreviations.

The dosage of drug required for a particular patient may mean that the unit of weight will need converting. **TABLE 2** illustrates how to convert from one unit of weight to another. To convert from a

A baby weighing 780 g needs a dopamine infusion of 5 mcg/kg/min for hypotension. The dopamine ampoule contains 40 mg/mL. The infusion is to be made up to 36 mL with 5% dextrose. How much dopamine needs to be added to the syringe if the rate is 0.5 mL/hr?

There are several steps involved in working out this calculation. The first step is to work out the amount of drug the baby needs.

Baby weight conversion

The baby's weight needs converting to kg: 780 g ÷ 1000 = 0.78 kg

Next, the amount of drug the baby requires should be calculated.

5 mcg x 0.78 kg/min = 3.9 mcg/min

Rate conversion

As the dopamine is to be given as an infusion, the next step is to work out how much the baby will require each hour, as currently the amount is per minute.

3.9 mcg x 60 minutes = 234 mcg/hour

The infusion is to be made up to 36 mL. As the infusion is to run at 0.5 mL/hr this means that 1 mL will infuse in 2 hours and 36 mL will take 72 hours* to infuse.

Therefore the amount to be added to the syringe is 234 mcg x 72 hours = 16,848 mcg.

Drug weight conversion

40mg/mL of dopamine needs converting into micrograms: 40 mg x 1000 = 40,000 mcg

Thus the calculated amount needed is:

$$\frac{16{,}848 \text{ mcg (prescribed dose)}}{40{,}000 \text{ mcg (dose of drug available)}} \times 1 \text{ mL (volume of drug)} = 0.4212 \text{ mL}$$

So 0.42 mL needs to be drawn up from the dopamine vial to be added to 35.6 mL of 5% dextrose.

* Please note that whilst the syringe in this example contains 72 hours worth of infusate this would still be changed daily as dopamine becomes unstable after 24 hours.

BOX 1 Example of a drug calculation incorporating baby weight, drug weight and rate conversions.

A baby requires a 240 mcg injection of morphine. The vial of morphine contains 1 mg/mL.

In order to calculate how much morphine the baby needs a weight conversion must be done as the units of weight are different.

Thus,

To convert 1 mg into micrograms the following calculation is made:

1 mg x 1000 = 1000 micrograms.

This conversion enables the drug calculation to be worked out as follows:

$$\frac{240 \text{ mcg}}{1000 \text{ mcg}} \times 1 \text{ mL} = 0.24 \text{ mL}$$

BOX 2 Drug weight conversion example.

A baby weighing 1.2 kg is prescribed 1.5 mg per kg as a total daily dose, to be given at 6 hourly intervals. How much should be given per dose and how many times a day should the child receive the medicine?

In this example firstly the total daily dose requires calculating.

1.5 mg/kg x 1.2 kg = 1.8 mg Total daily dose per 24 hours

Next the number of doses a day requires working out.

24 hrs ÷ 6 (hours) = 4 times/day

Lastly the amount needed at each dose can be calculated

1.8 mg/day ÷ 4 = 0.45 mg/ dose

BOX 3 Dosage frequency calculations.

higher unit of weight to a lower one multiply by 1000, alternatively, to convert from a lower unit of weight to a higher divide by 1000. When conversion is required it is preferable to convert the higher unit of weight to the lower one.

This ensures that the figures remain as whole numbers rather than including decimal places and helps to reduce the potential for the decimal place to be positioned incorrectly. See **BOX 2** for a worked example.

Volume

The most commonly used units of volume within children's nursing are millilitres (mL). Generally, IV infusion solutions come in one litre bags (equivalent to 1000 mL), but in practice neonatal and paediatric nurses will commonly use 500 mL bags. The ability to convert from one measure of volume to another is important. To convert litres to millilitres, multiply the number of litres or part litres by 1000. To convert millilitres to litres, divide the number of millilitres by 1000.

It is preferable to convert volumes to maintain whole numbers within the calculation rather than using decimal points.

Rate

It is important to follow the guidelines for the length of time over which a drug can be administered. This prevents any complications that may occur from the drug being given too rapidly or slowly. For example, acyclovir must be infused slowly over one hour[9] to prevent renal tubular damage[10].

In addition, for drugs where the dose is prescribed as a number of micrograms per minute, remember that for infusions the amounts need to be calculated for an hour's worth of infusate. For a worked example see **BOX 1**.

Dosage/frequency

Most drugs have to be given more than once a day, at specified time intervals. Not all information on drugs is provided in this format. It is important that nurses are able to calculate the time interval between doses and how much should be given per dose. See **BOX 3** for a worked example.

Weight/volume

The amount of drug in a given volume can also be expressed in more than one way. The most common of these that a neonatal/paediatric nurse may encounter are reviewed below.

Weight in volume expressed as a percentage

When a drug is expressed as a percentage this indicates the number of grams in 100 mL of diluent, e.g. a 1% solution is 1 gram of drug in every 100 mL of fluid. See **BOX 4** for worked example.

Moles and millimoles

The strength of intravenous infusion fluids and the concentration of substances in body fluids are often expressed in millimoles per litre (mmol/L). For the purposes of most calculations a mole or a millimole can be regarded as an amount, but it actually refers to a certain number of atoms or molecules.

A millimole is one thousandth of a mole. Thus 1,000 mmol = 1 mole.

For medications prescribed in mmol the formula for calculation remains the same. See **BOX 5** for worked example.

Other options

Some drugs are expressed as 1 in 1000 or 1:10,000 solutions, for example, adrenaline.

Similarly to the previous example, this denotes a specific amount of drug in a given volume.

1 in 1000 is 1g in 1000 mL solution

1 in 10,000 is 1g in 10,000 mL solution

Displacement values

Displacement values need to be accounted for whenever reconstitution from a dry powder or crystalline form is required. Whilst displacement values are of no interest if a complete vial is to be given, for smaller children and neonates this is often not the case. The displacement value can affect the amount of drug given if it is not taken into account.

The easiest way to address this is to consider the displacement value as part of the final volume. Thus, the displacement value needs to be subtracted from the total volume of fluid that would be used to reconstitute the vial. Neonatal and paediatric textbook drug guides are commonly used and contain specific information for these population groups[9,11].

Dilutions

There are two main reasons for diluting medicines within neonatology and paediatrics. Firstly the dosages required are usually very small. Sometimes the volume required is so small that it is not straightforward to measure it accurately. See **BOX 6** for a worked example.

Secondly some drugs require further dilution for reasons such as viscosity and/or irritation of veins, e.g., phenobarbitone should be diluted by 10 times the volume of drug drawn up[9].

Care must be taken to ensure that an adequate amount of diluent is added otherwise the drug may not dissolve completely. Other complications include administration of too strong a solution, which may result in infiltration and/or extravasation.

A baby is prescribed 84 mg of 4.2% of sodium bicarbonate. What volume does the child need to receive the right dose?

A 4.2% solution of sodium bicarbonate will contain 4.2 g of sodium bicarbonate per 100 mL of solution.

First convert the 4.2 g into milligrams so that the units of drug weight are the same.

4.2 g x 1000 = 4200 mg

Next work out how many mL of solution the baby should receive.

$$\frac{84 \text{ mg}}{4200 \text{ mg}} \times 100 \text{ mL} = 2 \text{ mL}$$

BOX 4 Calculating drugs expressed as percentages.

A baby is to receive 3 mmol of potassium chloride by infusion. The vial contains 20 mmol per 10 mL of potassium chloride. How much of this solution should be added to the infusion?

The infant needs 3 mmol of potassium

We have 20 mmol in each 10 mL of solution

The units are the same so no conversion is required

Thus:

$$\frac{3 \text{ mmol}}{20 \text{ mmol}} \times 10 \text{ mL} = 1.5 \text{ mL}$$

BOX 5 Drug calculation expressed in mmols.

The baby needs 0.1 unit of insulin/hour. The insulin vial contains 100 units/mL. What dilutions would you make to prepare a 30 mL syringe to deliver a dose of 0.1 unit/mL?

If this calculation were worked through as normal

$$\frac{0.1 \text{ unit}}{100 \text{ units}} \times 1 \text{ mL} = 0.001 \text{ mL}$$

It is not possible to draw up 0.001 mL accurately and thus it would be very difficult to administer the correct concentration of insulin to the baby using this method.

Thus in this instance it is helpful to use the following:

In 1 mL there are 100 units of insulin therefore:

In 0.1 mL there are 10 units of insulin.

Draw 0.1 mL of insulin solution up into a syringe and make this up to 1 mL with diluent.

This gives a total concentration of 10 units in a mL. This is a much more manageable way to calculate the amount needed for this baby.

$$\frac{0.1 \text{ unit}}{10 \text{ units}} \times 1 \text{ mL} = 0.01 \text{ mL}$$

As the syringe hold 30 mL that is 30 hours of infusion. Thus the above dose volume of 0.01 mL needs to be multiplied by 30.

0.01 mL x 30 = 0.3 mL

This can then be added to a syringe of 29.7 mL diluent making a total of 30 mL in the syringe.

This gives us an infusion concentration of 3 units in 30 mL

Which is equivalent to 1 unit in 10 mL = 0.1 unit/mL

BOX 6 Dilution of small volumes calculations.

The above examples highlight the complexity of drug calculations for neonatal and paediatric patients and therefore the room for medication error is increased.

Common medication errors

An adverse drug event (ADE) and a medication error are not the same thing. An ADE is an occurrence that can happen without an error having been made, e.g. an allergic reaction to a drug that wasn't previously identified in that individual, whereas a medication error is defined as "any preventable event that may cause or lead to inappropriate medication use or patient harm while the medication is in the control of the health care professional, patient or consumer"[12].

1. Quiet location dedicated for checking/preparing drugs to prevent distractions.
2. Know the drug or know where to find out about the drug – actions, interactions, side effects, contraindications, methods of dilution, displacement values and compatibilities.
3. Check the patient identification – weight, condition, allergies and other current medications.
4. Avoid decimal points when undertaking drug calculations to minimise risk of tenfold error. If a decimal point is unavoidable remember to use a leading zero if the amount is less than 1 millilitre. Do not use trailing zeros, e.g. 1.0, this can easily lead to a tenfold error.
5. Always include the units of measure when doing calculations as this can bring discrepancies in the units being used to the attention of the checker.
6. Abbreviations are easily misinterpreted so do not use them.
7. Ensure prescriptions are written correctly – clearly, in print, with units of measurement written out in full, with current patient weight, signed and dated.
8. Always refer to the local Trust drug information sources if you are unsure. If still in doubt seek help from other members of the multidisciplinary team or the pharmacy helpline.
9. Comply with local Trust policies and guidelines.
10. Adhere to preparation and administration instructions – correct diluent, correct pH, correct time over which drug should be given.

BOX 7 Top ten tips for reducing errors.

Wrong medicine	Wrong patient	Inadequately trained staff
Wrong route	Wrong labelling	Inappropriate abbreviations
Wrong concentration	Wrong dispensing	Excessive workload
Wrong fluid	Ambiguous labels/packaging	Distractions
Wrong rate	Similar/confusing drug name	Individual performance lapse
Wrong time	Illegible handwriting	Unavailable medication
Unauthorised administration	Incorrect dose calculation	
Omission of administration		

TABLE 3 Common drug errors.

It is important to acknowledge that however good the systems in place are, it is still inevitable that some errors will occur purely through the law of averages. Indeed, Leape[13], suggested that a 600 bed teaching hospital with 99.9% error free drug ordering, dispensing and administration, would experience approximately 4,000 drug errors a year. The DH suggested that 70% of errors are preventable[14] but in order to be able to minimise these events, first it must be understood why they occur (**TABLE 3**).

Many authors have cited a variety of reasons for medication errors occurring[5,15-18]. Ridley et al[8] suggested categories of errors including decision making, prescription writing, and transcription and prescribing errors depending on the clinical situation. A recent systematic review[19] found that dosing errors are the most common in children.

Another aspect of medication errors that should be considered is informing parents. Best practice would recommend that parents are informed of all medication errors and near misses. In reality however, it is unlikely that this happens. In one study[15], nearly half of the parents were not informed that a medication error had occurred. There were several reasons given for this, from "no harm was done" to "by the time they visited it was felt it would cause undue stress". While these reasons may seem plausible there may be both a clinical and ethical impact upon health professionals, children and families. If the error subsequently comes to light then the trust established between the professionals and parents would be damaged.

Additionally, there may be grounds for parents or a child to take matters further as there is increasing evidence that patients and their caregivers should be included in decision making and treatment regimes[20-23].

Taxis and Barber[6] identified the two most vulnerable stages when preparing and giving IV therapy. The first was in the preparation of the drug where multiple steps were needed and the second was in the giving of the drug when it was a bolus dose.

Nurses bear a huge responsibility when involved in IV drug administration as their task is not only to prevent themselves from making any errors in the preparation and giving of the drug, but also to recognise and resolve any errors made by the doctor and/or pharmacist who prescribe and provide the drug for administration.

The Government report 'Building a safer NHS for patients'[2], likened medication errors to an iceberg with only the tip showing. The majority of errors or near misses are not reported for a variety of reasons such as fear of reprisal or the people involved being unaware that an error has occurred. This may seem disheartening but on a more positive note Ross et al[15] noted that more nurses are reporting medication errors.

Minimising the potential for error

It could be suggested from the evidence presented that the majority of human error could be minimised with the introduction of two main strategies. Firstly, basic training complemented by regular updating is essential[2,21,24], preferably on an annual and mandatory basis. Indeed, the Royal College of Nursing document, 'Standards for Infusion Therapy'[23] and Nurses' Code of Professional Conduct[25] make this abundantly clear. Secondly, a culture where near misses, medication errors and adverse events are analysed through incident reporting to assess what can be done to prevent similar occurrences must continue within the NHS. This would benefit not only the patients, but also health professionals, as a person is only as good as the framework in which they are expected to perform[1,14].

In addition, due to the complex calculations and dilutions that may be required in neonatal or paediatric drug preparation and administration, double checking should be used at all times[2]. This is particularly important as it is reported that junior doctors do not receive adequate training in prescribing[26,27] so nurses are often the last defence in error prevention. See **BOX 7** for a summary of points to minimise medication errors in practice.

Use of drugs in the neonatal population

When discussing drugs used within neonatal and paediatric populations, it is important to be aware that not all drugs prescribed have been approved for that particular use by the manufacturer. When a drug is used for a population that its license or marketing authorisation (MA) does not cover, then this is classed as a drug being given off-label[28]. If a drug has no MA and yet is still used, this is unlicensed use.

When a drug is used off-label it means that no data has been presented to the licensing authority as to whether the drug is safe for use within this population. Certainly, for the neonatal population it would probably not be cost-effective for the manufacturers to carry out research as the target population is very small. Recently the House of Lords estimated that 90% of drugs administered to neonates and 50% of drugs given to children are unlicensed or off-label[29]. This illuminates the extent of the problem which neonatal and paediatric nurses face. Given such wide usage of off-label drugs it is important that nurses are aware of the lack of available evidence and the impact this has on clinical governance and risk management issues. Therefore, the use of unlicensed and off-label medications within neonatal and paediatric practice not only potentially increases the number of ADEs (due to the unknown aspects of the drug) but may contribute to the persistence of medication errors in the future. This is currently being addressed by the European Union[30,31] and the UK Government[21,32], with strategies being put in place to help both manufacturers of drugs and clinicians who use them to address this problem. These include strategies such as better reporting of ADEs when off-label drugs have been used and extra pharmaco-vigilance when using off-label medicines[33].

Conclusion

This article has reflected upon the importance of accuracy and competence throughout the whole process of drug therapy from prescribing to administration. Evidence to support the occurrence and likelihood of medical error due to systems failure is all too familiar within health professional literature. However, the promotion of best practice in relation to medication administration is not an impossible task even within the ever changing demands of today's NHS. Time is often the common dominator which governs service provision and the quality of care delivered. Knowledge of this factor alone may help the healthcare professional be more diligent in applying a safety conscious approach to the prescription, preparation and administration of drugs. High quality training and regular practice reviews are also vital. These measures should reduce potential and actual errors and safeguard patients from the short and long term consequences of drug errors.

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