Clinical Mathematics for Anesthetists

http://healthprofessions.udmercy.edu/academics/na/agm/mathweb09.pdf

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"I only took the regular course…Reeling and Writhing, of course, to begin with,' the Mock Turtle replied; 'and then the different branches of Arithmetic — Ambition, Distraction, Uglification, and Derision."

Alice's Adventures in Wonderland, by Lewis Carroll

Objectives

Please keep in mind that all dosages in this document are for learning mathematics only. Please check with your colleagues or reliable published sources to determine appropriate dosage for your patients.

The purpose of this document is to collect mathematical tools useful in anesthesia practice and increase patient safety by helping providers avoid drug errors. While the five rights of drug administration[1] and attention to systems that prevent errors are fundamental, they are not mentioned here. Opioid-sparing and ERAS techniques (because of their reliance on continuous infusions) have increased the frequency of calculations needed in clinical anesthesia practice.

1. Convert fractions to ratio or decimal, decimals to percent, ratios to mg/mL or mcg/mL, percent solutions to mg or mcg/mL.
2. Know common SI (metric system) prefixes and be able to convert quantities between them.
3. Perform temperature conversions between Fahrenheit, Celsius, and Kelvin scales.

[1] Nursing Rights of Medication Administration

4. Calculate desired rate setting for IV infusion pumps, given weight, drug concentration, and desired dose.
5. Convert weights in pounds to kilograms.
6. Calculate mean arterial pressure.
7. Calculate FIO_2 when air is being used rather than N_2O.
8. Calculate ideal body weight when given actual weight and height in any units.
9. Calculate how long an E tank of oxygen will last at a given liter flow.

Math Tools Review

Further Reading

- Kee JL, Marshall SM. *Clinical Calculations*. 7th ed. 2013 (or newer editions).
- Drug Calculations for Health professionals- Quiz page[2]
- Shubert D, Leyba J. *Chemistry and physics for nurse anesthesia.* 2nd ed. 2013
- Cruikshank S. *Mathematics & Statistics in Anaesthesia.* Oxford Univ Press 1998

Basic Approaches

Four basic techniques for solving many math problems are: Dimensional analysis, proportions, desired & available, and Lester's Rule for IV infusions.

Dimensional analysis

To ***convert units***, *multiply by an identity* (these are sometimes called *conversion factors* and are shown in parentheses in the formulae below). Examples:

$$760\text{mmHg} \times \left(\frac{14.7\text{psi}}{760\text{mmHg}}\right) = 14.7\text{psi} \tag{1.1}$$

$$29.9\text{inHg} \times \left(\frac{1013\text{mBar}}{29.9\text{inHg}}\right) = 1013\text{mBar} \tag{1.2}$$

$$454\text{gm} \times \left(\frac{2.2\text{lb}}{1000\text{gm}}\right) = 1\text{lb} \tag{1.3}$$

$$\frac{50\text{microgm}}{\text{mL}} \times \left(\frac{1\text{mg}}{1000\text{microgm}}\right) = \frac{0.05\text{mg}}{\text{mL}} \tag{1.4}$$

2 http://www.testandcalc.com/quiz/index.asp

In each example, the fraction is an identity. For example, in formula 1.3, multiplying by an identity (2.2 lb = 1,000 gm) changes 454 gm into the equivalent weight in pounds. Multiplying any quantity by an identity doesn't change the underlying quantity, only the units it is expressed in.

Proportions

Proportions are used to determine the answers to questions like "How far can I go on a half tank of gas, if a full tank will let me drive 300 miles?" or, more pertinently, "How many mL of 0.75% bupivacaine do I need to draw up to give the patient 12 mg?" To solve this question, you calculate that 0.75% bupivacaine contains 7.5 mg/mL (see "Percentage solutions" below on this page), then set up and solve a proportion:

$$\frac{1\text{mL}}{7.5\text{mg}} = \frac{\text{x mL}}{12\text{mg}} \qquad (2.1)$$

$$(12\text{mg}) \times \frac{1\text{mL}}{7.5\text{mg}} = \frac{\text{x mL}}{12\text{mg}} \times (12\text{mg}) \qquad (2.2)$$

$$\frac{12}{7.5}\text{mL} = \text{x} \qquad (2.3)$$

And 1.6 mL = x

Diluting drugs: "Desired & Available"

The name *desired and available* is meant to indicate that you work from what you have available, diluting it to what you desire or need (i.e. a more useful concentration).

Some thoughts before beginning. Many medications:

- require dilution or reconstitution: e.g. phenylephrine, ephedrine, epinephrine, ketamine, vecuronium, remifentanil, and others.
- come in different concentrations- from one site to the next, sometimes even from one day to the next, as shortages dictate changes in supplier. It is *imperative* to read the concentration on the vial! Examples: ketamine (10, 50, or 100 mg/mL), epinephrine (1:1,000, 1:10,000, and 1:100,000), neostigmine (0.5 or 1 mg/mL), etc.

Example 1: Ephedrine. You have ephedrine 50 mg in 1 mL. You want to prepare a syringe with 10 mg/mL. What size syringe should you use? In the second step, you set up a proportion to answer the question, *If the final concentration is to be 10 mg/mL, how much diluent do you add to 1 mL of ephedrine (50 mg/mL)?*

Available Ephedrine 50 mg in 1 mL vial

Desired

$$\frac{1\text{ mL}}{10\text{ mg}} = \frac{\text{x mL}}{50\text{ mg}} \qquad (3.1)$$

$$50\text{ mg} \times \frac{1\text{ mL}}{10\text{ mg}} = \frac{x\text{ mL}}{50\text{ mg}} \times 50\text{ mg} \tag{3.2}$$

Solving step 3.2 gives 5 mL total volume. So, take the 1 mL Ephedrine from the vial and add 4 mL sterile diluent in a 5 mL syringe.

Example 2: Remifentanil. If you want to create a remifentanil infusion at the recommended adult dilution of 50 mcg/mL, and it is supplied as a vial containing 1 mg powder[3], how many mL of diluent should you add to the vial?

The first proportion (step 3.3) cannot be solved as it is, since the denominator is in milligrams (on the left) and micrograms (on the right). So, in step 3.4, we multiply the right side by an identity (i.e. conversion factor) which changes the denominator on the right side of the equation to mg, like the left.

$$\frac{x\text{ mL}}{1\text{mg}} = \frac{1\text{mL}}{50\text{mcg}} \tag{3.3}$$

$$\frac{x\text{ mL}}{1\text{mg}} = \frac{1\text{mL}}{50\text{mcg}} \times \left(\frac{1000\text{mcg}}{1\text{mg}}\right) \tag{3.4}$$

$$\frac{x\text{ mL}}{1\text{mg}} = \frac{1000\text{mL}}{50\text{mg}} \tag{3.5}$$

$$(1\text{mg}) \times \frac{x\text{ mL}}{1\text{mg}} = \frac{1000\text{mL}}{50\text{mg}} \times (1\text{mg}) \tag{3.6}$$

And thus, x = 20 mL. Take the 1 milligram of remifentanil and add 20 mL diluent, which will result in a final concentration of 50 mcg/mL.

Example 3: Ketamine You have ketamine 500 mg in 5 mL. You want to prepare a 10 mL syringe with 10 mg/mL. In the first step, you figure out where you are going (by finding the total drug mass that needs to be in that syringe). In the second step, you determine what volume you need to withdraw from the vial to get the total drug mass you want in the syringe.

Desired $$\mathbf{\frac{10\text{ mg}}{1\text{ mL}} \times 10\text{ mL} = 100\text{ mg (total drug in 10 mL)}} \tag{3.7}$$

[3] Remifentanil is supplied as a powder, in vials containing 1, 2, or 5 mg. https://www.rxlist.com/ultiva-drug.h.='\;['tm#description

Available $$\frac{500\ \text{mg}}{5\ \text{mL}} = \frac{100\ \text{mg}}{\text{X mL}} \qquad (3.8)$$

Solving 3.8 gives 100 mg per 1 mL. Therefore take ketamine 1 mL from the vial (which gives the 100 mg total drug you want in your 10 mL syringe) and add 9 mL of diluent. Label it properly, of course, as containing 10 mg/mL ketamine.

Example 4: Epinephrine is available, marked "1/1,000" and "1 mg/mL." You are asked to "double-dilute" it, so you take 1 mL of the epinephrine 1:1,000 and add 9 mL diluent. Then you discard all but one mL of the new mixture, and add 9 mL diluent. What is the resulting concentration of epinephrine in micrograms/mL?

- Epi 1:1,000 contains 1 mg/mL (= 1,000 mcg/mL). Taking 1 mL and adding 9 mL diluent yields a syringe with 1,000 mcg/10 mL (100 mcg/1 mL).

- Taking 1 mL of this mixture (containing 100 mcg/mL) and adding 9 mL diluent to it yields a syringe containing 100 mcg/10 mL. Each mL of the “double-diluted” new mixture contains 10 mcg/mL.

Example 5: Epidural syringe preparation. Available: bupivacaine 0.25% (2.5 mg/mL), fentanyl 50 mcg/mL, and sterile diluent. Desired: A 60 mL syringe, containing 0.0625% (this is often called 1/16 %) bupivacaine with fentanyl 5 mcg/mL.[4]

Here’s Method 1: First, what is the total drug mass that you will end up with in the 60 mL syringe?

- Bupivacaine: 0.0625% contains 0.625 mg/mL.
  - How do we know this? *A percent solution means grams per 100 mL*. So 0.0625 % means 0.0625 grams of drug in 100 mL of solution (and 0.625 mg/mL).

$$\mathbf{\frac{0.0625\ g}{100\ mL} \times \frac{1,000\ mg}{1\ g} = \frac{62.5\ mg}{100\ mL} = \frac{0.625\ mg}{1\ mL}} \qquad (3.9)$$

- We want a 60 mL syringe with 0.625 mg/mL. The syringe will contain a total mass of bupivacaine of **37.5 mg** (= 60 mL * 0.625 mg/mL).

- The total mass of fentanyl in the syringe is desired to be 5 mcg/mL * 60 mL = **300 mcg**.

Now we are ready to prepare the 60 mL syringe:

[4] Please keep in mind that all dosages in this document are for learning mathematics only. Please check with your colleagues to determine an appropriate concentration & dosage to give to your patients!

- The total drug mass of bupivacaine is 37.5 mg/60 mL. Take the bupivacaine 0.25% (2.5 mg/mL) and **draw up 15 mL** (37.5/2.5 mg = 15) in the 60 mL syringe.
- The total drug mass of fentanyl is 300 mcg/60 mL. Take the fentanyl (50 mcg/mL) and **draw up 6 mL** in the 60 mL syringe. The total volume you have drawn up so far is 15 mL (bupivacaine) + 6 mL (fentanyl) = 21 mL.
- Add 39 mL diluent to achieve a total volume of 60 mL.

What if, for some reason, you had to prepare a 20 mL syringe? (Let's say you only happen to have a 20 mL syringe at hand.) The method is the same, if the same final concentration is desired.

- Bupivacaine: 0.0625% contains 0.625 mg/mL.
    - We want a 20 mL syringe with 1/16% (0.625 mg/mL). A 20 mL syringe will contain a total mass of bupivacaine of **12.5 mg** (= 20 mL * 0.625 mg/mL).
- The total mass of fentanyl in the syringe is desired to be 5 mcg/mL * 20 mL = **100 mcg**.

Now we are ready to prepare the 20 mL syringe:

- The total drug mass of bupivacaine is 12.5 mg/20 mL. Take the bupivacaine 0.25% (2.5 mg/mL) and **draw up 5 mL** (= 12.5/2.5 mg) in the 20 mL syringe.
- The total drug mass of fentanyl is 100 mcg/20 mL. Take the fentanyl (50 mcg/mL) and **draw up 2 mL** in the 20 mL syringe. The total volume you have drawn up so far is 5 mL (bupivacaine) + 2 mL (fentanyl) = 7 mL.
- Add 13 mL diluent to achieve a total volume of 20 mL.

Here's Method 2: I find it (much) easier to make the calculation of total drug mass for bupivacaine in the 60 mL syringe in another way.

It is easy to see that the same drug mass is present in two solutions, the second of which is twice as concentrated as the first, but contains only half the volume. Therefore, all the rows below contain the same total mass of drug. The first row starts with what you want to end up with, and proceeds down to what you need to start with.

> "Bupivacaine 60 mL of 1/16% contains the same mass of drug as 30 mL of 1/8%.
> Bupivacaine 30 mL of 1/8% contains the same mass of drug as 15 mL of 1/4%."

Concentration of bupivacaine	Volume	Total mass of drug present
1/16 % (= 0.0625% = 0.625 mg/mL)	60 mL	37.5 mg
1/8 % (= 0.125% = 1.25 mg/mL)	30 mL	37.5 mg
1/4 % (= 0.25% = 2.5 mg/mL)	15 mL	37.5 mg

So, to prepare a 60 mL syringe with bupivacaine 1/16%, and fentanyl 5 mcg/mL: draw up bupivacaine (1/4 %) 15 mL, add fentanyl 6 mL (x 50 mcg/mL = 300 mcg), and finally add 39 mL of diluent.

Similarly, to prepare a 20 mL syringe with bupivacaine 1/16%, and fentanyl 5 mcg/mL: draw up bupivacaine (1/4 %) 5 mL, add 2 mL fentanyl, and finally add 13 mL of diluent.

Example 6: Dexmedetomidine preparation, loading, maintenance. Available: dexmedetomidine 200 mcg/2 mL. Add to 48 mL 0.9% normal saline, yields concentration of 4 mcg/mL. For procedural sedation, or as adjunct to general anesthesia[5]

	Dose*	Volume of 4mcg/mL dilution (for 70 kg)	Rate mL/hr
Loading Dose	0.5 mcg/kg/10 min	8.75 mL/10 min	52.5 mL/hr (*for 10 min only*)
Maintenance	0.5 mcg/kg/hour	8.75 mL/hr	8.75 mL/hr continuous

*Dose range for loading 0.5 to 1 mcg/kg/10 min; for maintenance 0.5 to 1 mcg/kg/hr. Base dose on LBW (Lean Body Weight) in morbidly obese.[6]

Lester's No-Math Rule for Intravenous Infusions

Lester's No-Math Rule for intravenous infusions is:

> *The number of mg in 250 mL comes out in mcg in 1 min. at a setting of 15mL/hr*, (and)
> *The number of grams in 250 mL comes out in mg in 1 min. at a setting of 15mL/hr*.

- Why 15 mL/hr? At that rate, the volume delivered is 0.25mL (1/1,000 of a 250 mL bag) per minute.

$$\frac{15\text{mL}}{1\text{hr}} \times \left(\frac{1\text{hr}}{60\text{min}}\right) = \frac{15\text{mL}}{60\text{min}} \qquad (4)$$

- And by division, 15 mL/60 min = 0.25 mL/min.
- 0.25 mL is a very useful quantity- it is 1/1,000 of a 250 mL IV bag. Because it is 1/1,000th of the volume, 0.25 mL contains 1/1,000 of the mass of drug in the whole 250 mL bag.

[5] https://www.drugs.com/dosage/precedex.html
[6] *Br J Anaesth* 2010;105(Suppl_1):i16 doi: 10.1093/bja/aeq312; *Br J Anaesth* 2018;120:969. doi: 10.1016/j.bja.2018.01.040

If this whole bag contains **Dopamine 400 mg in 250 mL**…

Then in each 0.25 mL (**1/1,000th** of the **volume**), there is **1/1,000th** of the **drug mass** the entire bag holds.

- 400 mg x 0.001 = 0.4 mg = **400 mcg**
- 250 mL x 0.001 = **0.25 mL**

Examples of Lester's No-Math Rule:

1. What is the dose of lidocaine (1 gm in 250 mL) running at 15 mL/hr? *1 mg/min*. At 30 mL/hr? *2 mg/min*. At 60 mL/hr? *4 mg/min*.

2. What is the dose of epinephrine (1 mg/250 mL) running at 15 mL/hr? *1 microgm/min*. At 30 mL/hr? *2 microgm/min*. At 60 mL/hr? *4 microgm/min*.

3. What rate should you set to deliver dopamine 3 mcg/kg/min for a patient who weighs 70 kg? The dopamine concentration is 400 mg/250 mL.
    - *7 mL/hr will deliver 200 microgm/min, which is approximately 3 microgm/kg/min.*

Fraction, Ratios, & Decimals

- Fractions and ratios are *nearly* identical, except when the numerator and denominator are small. For example, 1/3 signifies 0.33, but 1:3 signifies a ratio of 1 part to 3 parts (and thus 4 parts in total) or 0.25.
- To convert a fraction to a decimal

$$1 \div 3 = 0.3333 \tag{5}$$

- To convert a decimal to a percent, divide, then multiply by 100.

$$(0.3333) \times 100 = 33.33\ \% \tag{6}$$

Ratios in anesthesia

- Ratios are expressed in **grams/mL** (recall that 1 mL of H_2O weighs very close to 1 g).
- The ratio 1:100,000 is frequently encountered. So (starting with 1 gm in 100,000 mL), take the following steps to determine the number of microgm/mL in a 1:100,000 solution. The fractions in parentheses are conversion factors:

$$\frac{1\text{gm}}{100{,}000\text{mL}} \times \left(\frac{1000\text{mg}}{1\text{gm}}\right) = \frac{1000\text{mg}}{100{,}000\text{mL}} \tag{7.1}$$

$$\frac{1000\text{mg}}{100{,}000\text{mL}} \times \left(\frac{0.001}{0.001}\right) = \frac{1\text{mg}}{100\text{mL}} \tag{7.2}$$

$$\frac{1\text{mg}}{100\text{mL}} \times \left(\frac{1000\text{microgm}}{1\text{mg}}\right) = \frac{1000\text{microgm}}{100\text{mL}} \qquad (7.3)$$

$$\frac{1000\text{microgm}}{100\text{mL}} \times \left(\frac{0.01}{0.01}\right) = \frac{10\text{microgm}}{1\text{mL}} \qquad (7.4)$$

So a solution containing epinephrine 1:100,000 has 10 microgram of epinephrine per mL. By the same logical steps, a solution marked 1:200,000 has 5 microgram epinephrine per mL, and a solution marked 1:1,000,000 has 1 mcg/mL.

Percentage Solutions

- The "*number of parts of drug in every hundred*" is the percentage of a solution, which is conventionally expressed as "**grams per 100 mL**". Drugs commonly labeled as % include local anesthetics, & magnesium.
- "**To find the mg/mL in a % solution, move the decimal point one place to the right**" is the shortcut. For example, a 1% solution (1 g/100 mL) has 10 mg/mL:

$$\frac{\mathbf{1\ g}}{\mathbf{100\ mL}} \left(\times \frac{0.01}{0.01}\right) = \frac{0.01\text{ g}}{1\text{ mL}} \left(\times \frac{1000\text{ mg}}{1\text{ g}}\right) = \frac{\mathbf{10\ mg}}{\mathbf{1\ mL}} \qquad (8)$$

Two easier ways to do frequent calculations

1. Convert pounds to kg (Pilchak's No-Math Rule)

To quickly convert pounds to kilograms (a formula that's easy to do in your head): *"Take half the weight in pounds, then subtract another 10%."*

$$\left(\frac{\text{Pounds}}{2}\right) - 10\% = \text{Weight kg} \qquad (9)$$

2. Calculate mean arterial pressure (MAP)

The heart spends two-thirds of each cycle in diastole. So we calculate a weighted average that takes this time factor into account. Most of us learned to do it by the following (equation 10). To me this is slightly cumbersome (three steps needed--multiply, add, divide).

$$\frac{\text{Systolic pressure} + (\text{Diastolic } \times 2)}{3} = \text{MAP} \qquad (10)$$

- For example, 120/60:

$$\frac{120 + (60\ \times 2)}{3} = 80$$

Try this second method instead. While it too has three steps (subtract, divide, add), it is simpler (in your head, adding or subtracting are easier than multiplying or dividing).

$$\frac{\text{Systolic} - \text{Diastolic}}{3} + \text{Diastolic} = \text{MAP} \tag{11}$$

- For example,

$$\frac{120 - 60}{3} + 60 = 80$$

Ideal Body Weight (IBW) Estimation- two methods

Why is this important? 1. To protect the lungs from ventilator-associated lung injury, we use tidal volumes (VT) of 5-7 mL/kg *ideal body weight*. After all, the lungs don't get bigger when body weight is excessive. For example, ventilating a male of average height (69 in) weighing 325 lbs (BMI = 48)[7] at 7 mL/kg using

- actual body weight (ABW), we would use VT = 1,023 mL
- using IBW (approximately 72 kg), VT = 504 mL.

2. Another important reason for calculating IBW is because the basis for drug dosages differs:[8]

- **Dose based on <u>Ideal (or Lean) BW</u>**: propofol (induction), NDMR (e.g. rocuronium, cis-atracurium), narcotic loading dose, remifentanil, Tidal Volume, dexmedetomidine (LBW).
- **Dose based on <u>Actual BW</u>**: propofol (maintenance), sugammadex[9], succinylcholine, narcotic maintenance (fentanyl, sufentanil), thiopental, midazolam.

Regardless of which method of calculating IBW you choose, keep in mind that *none of these work well at extremes of height* (particularly for females whose height is < 60 in). There are excellent discussions of IBW online[10] and in print.[11] Also, "*these formulas have no method to compensate for Age and Current Weight*. They are only based on Height. For people who are very overweight or obese, the Devine, [and other] formulas would suggest an ideal weight that is virtually impossible to achieve or maintain through dieting."[12]

1. **Simple rule**[13] Easy to remember, since we most often think of height in inches and feet:

$$\text{Females} = 100\text{ lb} + (5\text{lb/inch over 5 ft}) \tag{12.1}$$

$$\text{Males} = 105\text{ lb} + (6\text{lb/inch over 5 ft}) \tag{12.2}$$

[7] https://www.nhlbi.nih.gov/health/educational/lose_wt/BMI/bmicalc.htm
[8] *AANA Journal* April 2011: 79 (2):147; *Br J Anaesth* 2010;105(Suppl_1):i16; Nagelhout & Elisha. *Nurse Anesthesia* 6th ed. p. 1007
[9] https://www.merckconnect.com/static/pdf/bridion-sugammadex-dosing-considerations.pdf
https://onlinelibrary.wiley.com/doi/10.1111/j.1365-2044.2011.06782.x
[10] https://halls.md/ideal-weight-formulas-broca-devine/
[11] Martin and Richards *BMC Pulmonary Medicine* (2017) 17:85, doi 10.1186/s12890-017-0427-1
[12] https://halls.md/ideal-weight-formulas-broca-devine/
[13] Nagelhout & Elisha. *Nurse Anesthesia* 6th ed. P. 320. Also see p. 998, which gives a rule similar to Broca's.

- Devine (1974) converted this simple rule to metric (the conversion is approximate). An electronic medical record (Epic) uses this formula to calculate IBW (I am told). Note- also called *Predicted Body Weight (PBW).*[14]

$$\text{Females IBW kg} = 45.5\text{ kg} + 2.3\text{ kg/each inch over 5 feet} \tag{12.3}$$
$$\text{Males IBW kg} = 50\text{ kg} + 2.3\text{ kg/each inch over 5 feet} \tag{12.4}$$

2. **Body Mass Index (BMI)** is a way to relate the actual weight to the ideal. Be sure to specify height in meters squared. Normal BMI is less than 25, obese is less than 28, morbid is more than 35. To use this to find IBW, set BMI to 25 and solve for weight. Hall suggests using BMI of 23.0 for males, and 21.1 for females to estimate IBW.[15]

$$\text{BMI} = \frac{\text{Weight kg}}{\text{Height (meters}^2)} \tag{12.5}$$

Lean Body Weight (LBW)

Although less often used, "Lean" BW refers to the weight of all body tissues (muscle, bone, organs) *without fat*. LBW is a way to determine the percentage of the obese weight that is metabolically active (also known as "adjusted" BW). It might be reasonable to calculate fluids or drugs in morbidly obese individuals based on metabolically-active tissue weight – the Lean BW.

Lean BW First Method

- The multiplier is between 0.2 and 0.5 of the difference between Actual and Ideal BW (median .32).[16] Nagelhout gives IBW x 1.3 = LBW.[17] Miller uses 0.2[18]

$$\mathbf{LBW = IBW + 0.2(ActBW - IBW)} \tag{13.1}$$

- For example, a male 6 ft 0 in. (1.83 m) and 270 lbs. (122.7 kg)
    - $\text{BMI} = \frac{122.7\text{ kg}}{3.34\text{ Ht (m}^2)} = 36.7$
    - $\text{IBW (using 25 BMI)} = 25 * 3.34 = 83.5\text{ kg}$ (183.7 lbs)
    - Lean BW (using formula 13.1) is 91.34 kg (200.9 lbs)
        - $91.34\text{ kg Lean BW} = 83.5\text{ kg} + 0.2(122.7 - 83.5\text{ kg})$

[14] Martin and *Richards BMC Pulmonary Medicine* (2017) 17:85, doi 10.1186/s12890-017-0427-1. Also see *N Engl J Med*. 2000;342:1301; http://www.ardsnet.org/files/ventilator_protocol_2008-07.pdf; and *Ann Pharmacother* 2000;34:1066.
[15] https://halls.md/ideal-weight-formulas-broca-devine/
[16] Nutr Clin Pract 2005;20(4):468
[17] Nagelhout *Nurse Anesthesia* 6th ed p. 998
18 Miller's Anesthesia 7th Ed. 2009. p. 2099.

Lean BW Second Method[19]

$$\text{Lean BW} = \text{BMI} * \text{Height } (\text{m}^2) \quad (13.2)$$

For Normal Body mass, Lean BW = Ideal BW	IBW=23*Ht (m^2)	IBW=21*Ht (m^2)
Morbidly Obese (IBW same as above)	LBW=26*Ht (m^2)	LBW=22*Ht (m^2)

- For example, a male 6 ft 0 in. and 270 lbs.
    - $\text{BMI} = \frac{122.7 \text{ kg}}{3.34 \text{ (Ht m)}^2} = 36.7$
    - IBW (using 23 BMI) $= 23 * 3.34 = 76.8$ kg (169 lbs)
    - and Lean BW $= 26 * 3.34 = 86.8$ kg (191 lbs)

Metric System

The metric system is also known as "SI" (Systeme Internationale). The NIST Metric System Teaching Site[20] has a wealth of information on every aspect of the metric system, very clearly presented. It's easier to learn if you start thinking of all your everyday quantities metrically- your height, your soda can, a jar of salsa- what is their volume and weight expressed in metric system units? A gram is 1000 mg, a mg is 1000 mcg, and a mcg is 1000 ng.

Metric Prefixes

Prefix	**Associated quantity**	**In scientific notation**
mega (M)	1,000,000	10^6
kilo (k)	1000	10^3
hecto (h)	100	10^2
centi (c)	0.01	10^{-2}
milli (m)	0.001	10^{-3}
micro (mc)	0.000001	10^{-6}
nano (n)	0.000000001	10^{-9}

Metric pressure units (the first two below), based on the Pascal, may be unfamiliar to those in US.

1 atmosphere equals	1 Bar 1000 hPa = 1,019 cm H_2O = 1,013 mBar 760 torr = 760 mm Hg 100 kPa 29.9 in Hg 14.7 psi

[19] *Br J Anaesth* 2012;109(5):829

[20] https://www.nist.gov/pml/owm/metric-si/si-units

Temperature Conversions

$$°C = 5/9\,(°F - 32) \tag{14.1}$$

$$°F = (9/5 \times °C) + 32 \tag{14.2}$$

Or **(better yet) remember the two together with**:

$$9 \times °C = (5 \times °F) - 160 \tag{14.3}$$

Also,

$$\text{Degrees Kelvin} = °C + 273 \tag{14.4}$$

Figuring oxygen concentration when air or N_2O are used

It is useful as a backup to know what your oxygen analyzer "should" read. You can calculate expected F_IO_2 in the total fresh gas flow (FGF). The total volume of oxygen includes all volume from the oxygen flowmeter, plus 21% of the volume indicated on the air flowmeter (and none of the rest of the flowmeters). Examples:

- What is the percent oxygen when 2 L/min oxygen and 2 L/min air are flowing? *60.5%*

$$2000\text{mL } O_2 + (0.21 \times 2000\text{mL Air}) = 2420\text{mL } O_2 \tag{15.1}$$

$$(2420\text{mL } O_2)/(4000\text{mL total FGF}) = 60.5\%\ O_2 \tag{15.2}$$

- What percent oxygen is inspired when FGF is 2 L/min O_2? 1 L/min O_2? 8 L/min O_2? *Answer: 100% in each case*
- What percent O_2 is inspired when FGF is 2 L/min O_2 + 2 L/min N_2O? *Answer: 50%*
- What percent O_2 is inspired when FGF is 1 L/min O_2 + 2 L/min N_2O? *Answer: 33%*

DOT-123

A clinical rule useful in (quick and roughly accurate) estimation of respiratory parameters for infants and children. For example, you would expect a VT of 21 mL in a newborn of 7 lb.

- Dead space = 1 mL per lb,
- O_2 consumption = 2 mL per lb, and
- Tidal Volume = 3 mL per lb.

Calculating how long a cylinder will last

A perennial Board-type question with clinical importance. Use this equation[21] to solve for minutes your E tank will last (there are approximately 660 L in a full E tank of oxygen, at a service pressure of 2200 psi).

Example: Your oxygen tank pressure gauge reads 1000 psi. How long can an O_2 flow of 2 L/min be maintained?

$$\text{Minutes remaining} = \frac{0.3 * Gauge\ pressure\ (psi)}{O_2\ flow\ (L/min)} \tag{16}$$

The tank will last 150 min, at an oxygen flow of 2 L/min.

Acceptable blood loss (ABL)

There are many online calculators on the web.[22] Try searching for "allowable blood loss calculator." Estimated blood volume (EBV) by age and gender:

		EBV mL/kg
Adults-	Male	75
	Female	65
Pediatrics-	Premature infants	90
	Neonate at term	85
	Children 1-2yr	75

Then calculate allowable blood loss

$$\text{ABL} = \frac{\text{Hct}_{\text{initial}} - \text{Hct}_{\text{final}}}{\text{Hct}_{\text{initial}}} \times \text{EBV} \tag{18}$$

Using this formula, you still have to decide what your transfusion trigger is: lowest acceptable hemoglobin, arterial oxygen content, or final hematocrit. While individuals vary, the allowable blood loss by the formula above may be too lenient. The **20% rule for ABL** (= EBV x 0.2) is an alternative approach to replacement (taking into consideration the procedure type/length and patient history).

For example, a 70kg male patient with hematocrit 42. EBV = 5,250 mL (75mL x 70kg):

- Using HCT rule (equation 18), ABL= 5,250mL x [(42-21)/42] = 2,625mL
- Using 20% rule, ABL = 5,250mL x 0.20 = 1,050mL

Again, taking into account the patient's history, current hemodynamic status, and procedure type and length, it seems more reasonable to begin thinking (not necessarily transfusing) about

[21] See Oxygen tank duration calculator or a similar calculator here. They use a conversion actor of 0.28 (based on E tank contents when full of 680 L at 2200 psi), but 0.3 is relatively easy to remember and accurate enough for the purpose

[22] http://manuelsweb.com/nrs_calculators.htm, or https://www.mdcalc.com/maximum-allowable-blood-loss-abl-without-transfusion

replacement earlier (at 1,050 mL blood loss rather than 2,625 mL). Of course, both of these formulas are to be used as guidelines, not absolute rules.[23]

Alternatively, using hemoglobin of between 6 to 10 g/dL in addition to patient history has been recommended.[24]

Fluid maintenance

Pediatric fluid balance:

1. For the first 10 kg, give 4mL/kg/hr, then (19)
2. For the next 10 kg (10-20 kg), give 2mL/kg/hr, then
3. Give 1mL/kg/hr for kg greater than 20 kg.

For example, a 12 kg child gets $(10 \times 4) + (2 \times 2) = 44\ \mathrm{mL/hr}$.
And a 22 kg child gets $(10 \times 4) + (10 \times 2) + (2 \times 1) = 62\ \mathrm{mL/hr}$

Adults

A fast way to calculate Maintenance/NPO fluid requirements on patients over 20kg: Instead of equation 19, you get the same results with:

$$(\text{Weight kg} + 40) \times \text{Hours NPO} = \text{NPO replacement mL} \qquad (20)$$

For example, 60kg female, NPO 8 hours
- Using equation 19: (4mL x 10) + (2mL x 10) + (1mL x 40) = 100mL x 8hrs NPO = 800mL
- Using equation 20: 60kg + 40 = 100mL x 8hrs NPO = 800mL

Endotracheal tube size, length (pediatric)

$$\text{ET internal diameter (mm)} = \frac{\text{Age} + 16}{4} \qquad (21.1)$$

$$\text{Lip line} = \frac{\text{Age}}{2} + 12 \qquad (21.2)$$

An equivalent formula which some use instead of 21.1:[25]
- Predicted Size Uncuffed Tube = (Age / 4) + 4
- Predicted Size Cuffed Tube = (Age / 4) + 3

[23] "…the [Pirate] Code is more what you'd call guidelines than actual rules." Hector Barbossa, *Pirates of the Caribbean: The Curse of the Black Pearl*
[24] See discussion in Nagelhout *Nurse Anesthesia* 6th ed p. 369-71
[25] https://www.mdcalc.com/pediatric-endotracheal-tube-ett-size citing *Clin Intensive Care*. 1991;2(6):345.

Alveolar air[26]

$$pAO_2 = F_IO_2(p_B - pH_2O) - 1.2 \times paCO_2 \tag{22.1}$$

Note how alveolar (and thus arterial) oxygenation can suffer if arterial CO_2 is elevated. Normal alveolar oxygen is

$$101.73 \text{ torr} = 0.21(760 - 47) - 1.2 \times 40 \tag{22.2}$$

But, if CO_2 increases to 60 torr, alveolar oxygen must fall from 101 to 77.7 torr (!). This equation assumes that pH_2O = 47 torr at body temperature, P_B is barometric pressure, and R is normal (R is the respiratory quotient, found by dividing CO_2 excreted by O_2 consumed).

Arterial oxygen content[27]

$$CaO_2(^{mL}/_{100mL\ blood}) = (1.34 \times Hb \times SaO_2) + (paO_2 \times 0.003) \tag{23}$$

Expected pO2 for changes in FIO2

A rough thumbnail estimator based on Henry's Law. If you increase FIO_2 10%, expect paO_2 to increase 50 torr (starting values FIO_2 21%, paO_2 100 torr approximately).

Time constant[28]

$$\text{Time Constant} = \frac{\text{Capacity}}{\text{Flow}} \tag{24}$$

- A system reaches 63% of equilibrium in one time constant; 86% of equilibrium in 2 time constants; 95% of equilibrium in 3 time constants. Applications are wash-in and washout of gases, or time to complete preoxygenation/ denitrogenation at varied fresh gas flow rates.

Remembering drug doses

It's always advisable with a family of drugs **to work out their relative doses per 70 kg**. That way, you have a baseline for comparison and can increase or decrease your starting dose in proportion to the patient's weight. Also, you're less likely to choose a much too big (or much too small) dose for a patient when you have memorized what the "average weight" patient would typically receive.

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26 ALveolar gas equation
27 Oxygen Content Calculator
28 https://derangedphysiology.com/ or here

- For example, reasonable intubating doses for the muscle relaxants (assume 70 kg weight) are vecuronium 7 mg, rocuronium 42 mg, cis-atracurium 14 mg, and pancuronium 7 mg. (Of course you would modify these doses based on body habitus and past history.)

Remember "same as…" doses. For example, vecuronium and pancuronium. Or similar doses like the pair esmolol (bolus 0.5 mg/kg) and rocuronium (roughly the same for a low-range intubating dose).

Work out doses for a typical person

Dose mg/kg	Dose/70kg
1	70 mg
0.5	35 mg
0.1	7 mg
0.05	3.5 mg
0.01	0.7 mg

Again, that way you have a concept of what those numbers mean for the "average" patient. You can then use this concept as a means of double-checking your answer derived from the electronic calculator, or for mental math done in haste.

Keep in mind the expected volume (number of mL) for usual doses of drugs, especially narcotics and muscle relaxants. If you are drawing up and preparing to administer more than 3 to 10 mL of muscle relaxant as an intubating dose, it is likely your math is faulty (provided the patient is anywhere near normal weight).

Spinal (intrathecal) doses

1. **Have somewhere to start for a reasonable level (T10) for each drug**.
    - For example tetracaine 10 mg (1 mL of 1%)
    - A reasonable lidocaine dose for the same effect is 50 to 60 mg (1 to 1.2 mL of 5%).
    - A reasonable bupivacaine dose is 12 mg (1.6 mL of 0.75%).
2. **Know the range of doses found to be useful at your institution, in your patients.** Modify the dose based on height, medical history, pregnancy, or whatever other factors you like**.**
    - When you add or subtract, remember the amount of drug in some usefully-small quantity (spinal syringes are marked every 0.2 mL)
        - lidocaine 5% has 10 mg per 0.2 mL,
        - tetracaine 1% has 2 mg per 0.2 mL , and
        - bupivacaine 0.75% has 1.5 mg per 0.2 mL.
3. **Alter the baricity of the drug, if needed, for the effect you want.** Typically, hyperbaric spinals are given. The spinal medications may or may not come mixed in hyperbaric 7-10% dextrose. If they do *not* come so mixed, add an equal volume of dextrose solution to the local anesthetic.

4. **Add any extras, have someone double-check your figures if you have the SLIGHTEST doubt** (once given, the medication is irretrievable and has profound effects), *then administer*.
    - Epinephrine (1:1000) 0.2 mL is a common additive.
    - Preservative-free morphine 0.5-0.7 mg (0.5-0.7 mL of Duramorph 0.1%) is also common, as is fentanyl.
    - Please don't ask me how I know about the "irretrievable and profound" part.

Epidural doses

1. The rule of thumb is **With a lumbar epidural placement, 10 mL of drug will generally produce a T7 to T9 level in the average size patient, 20 mL will result in a T4 level.**
2. Larger volumes of drug will be required for higher blocks, more concentrated drugs for more intense motor block, and more dosage (total mass of drug) for increased sensory block.[29]

Questions?
Return to Anesthesia Course Notes site at UDM.

[29] Reese CA. Spinal and epidural blocks. 2nd ed. Park Ridge, Illinois: AANA; 1996 p. 104-5