Chapter 1

DIAGNOSTIC TESTS AND ADVANCED FORMULAE

Acute Care for Nurses, First Edition. Claire Boyd.

LEARNING OUTCOMES

By the end of this chapter you will have an understanding of how to calculate mean arterial pressure (MAP), drug administration calculations, percentage strength of drugs, solution strength of drugs (e.g., mg/ml), infant feeding regimens, infant growth expectations, body surface area (BSA), and body mass index (BMI); how to measure cardiac output (CO); how to assess lung function and renal clearance; and how to determine energy requirements of the body.

Working in health care, we all need to have a good grasp of mathematics to perform our professional duties, such as keeping accurate fluid balance records (see Appendix 3), totting up the vital signs on the National Early Warning Score 2 observation chart (see Appendix 1), and administering medications, to name just three. As our careers progress, we may be involved in more complex mathematics. This may involve having an understanding of body organ and systems calculations. Even if you are not expected to undertake these calculations, it is still good to have the knowledge of how these readings are obtained and what they mean to the patient's health.

MEAN ARTERIAL PRESSURE

For instance, in Chapter 2 we will look at mean arterial pressure (MAP) of blood pressures (BPs) in relation to sepsis. This reading often pops up on automatic BP machines (electronic sphygmomanometers), but what exactly is it and how do we obtain this reading if using a manual sphygmomanometer (aneroid), as shown in Figure 1.1, with a stethoscope?

Figure 1.1 Aneroid sphygmomanometer.

GLOSSARY

Mean arterial pressure (MAP)

MAP is the average blood pressure of an individual during a single cardiac cycle and informs us whether the blood flow is adequately perfusing the tissues/organs. This is a vital calculation for patients in critical care and in cases of septic shock.

Working out the MAP from a BP recording is actually very simple:

Step 1: Take BP recording.
Step 2: Multiply the diastolic BP (DBP) by 2.
Step 3: Add this value to the systolic BP (SBP) and divide by 3.

Example: **BP: 120/80 mmHg**
DBP: $80 \times 2 = 160$
$160 + 120$ (SBP) $= 280$
Divide by 3 = **93.3**

Activity 1.1

ACTIVITY

1 Work out the MAP of BP 135/85 mmHg.
2 Work out the MAP of BP 120/70 mmHg.

DID YOU KNOW?

The normal MAP range is between 70 and 100 mmHg. The body needs at least 60 mmHg to provide enough blood to the coronary arteries, kidneys, and brain.

HEALTHCARE CALCULATIONS

Before we look at some more advanced body organ and systems calculations, we will first revise our more everyday or 'bread and butter' drug administration calculations.

Drug Dosages for Tablets/Capsules

$$\textbf{Formula}: \frac{\text{What you want (WYW)}}{\text{What you've got (WYG)}}$$

A patient has been administered 0.25 mg of digoxin orally. Stock: 250-microgram (μg) tablets. How many tablets do you administer?

First, change 250 μg to milligrams (mg):
250 μg/1000 = 0.25 mg.

WYW: 0.25 mg
WYG: 0.25 mg = 1 tablet

QUESTION

Question 1.1
Prescription: 8 mg morphine
Stock: 10 mg/2 ml
How much do you administer?

Drug Dosages for Injections, Syrups, Elixirs, Among Others

Formula: $$\frac{\text{What you want (WYW)}}{\text{What you've got (WYG)}} \times \text{Volume}$$

A patient requires a subcutaneous injection of 22 units. 10 ml stock ampoules contain 100 units to every 1 ml. What volume do you draw up?

$$\frac{\text{WYW}}{\text{WYG}} \times \text{Volume} : \frac{22 \text{ units}}{100 \text{ units}} \times 1 \text{ ml} = 0.22 \text{ ml}$$

QUESTION

Question 1.2 A patient is prescribed 400 µg of Granisetron syrup orally. Stock solution = 1 mg/5 ml. How much do you draw up?

Infusion Pump Rates (in millilitres per hour)

Formula: $$\text{Rate} = \frac{\text{Volume}}{\text{Time}}$$

A patient is to receive 4 l of 0.9% sodium chloride over eight hours. What is the infusion rate in millilitres per hour?

4 l = 4000 ml

$$\frac{\text{Volume}}{\text{Time}} = \frac{4000}{8} = 500 \text{ ml / h}$$

QUESTION

Question 1.3 350 ml of blood is to given to a patient over four hours. What is the infusion rate in millilitres per hour?

Drip Rates (in Drops per Minute)

Formula: $\frac{\text{Volume (ml)}}{\text{Time (h)}} \times \frac{\text{Drops per ml}}{\text{60 (minutes per hour)}}$

The patient has been prescribed 1 l of 5% glucose to run over eight hours. What is the infusion rate in drops per minute, using a standard administration set delivering 20 drops/ml?

Change 1 litre into ml = 1000 ml

$\frac{\text{Volume}}{\text{Time}} \times \frac{\text{Drops per ml}}{60} = \frac{1000}{8} \times \frac{20}{60} = 41.6 =$ **42 drops / min**

QUESTION

Question 1.4 Patient has been prescribed 0.5 l of fluid to run over five hours. What is the infusion rate in drops per minute, using a blood administration set delivering 15 drops/ml?

Duration of Infusions

Formula: $\frac{\text{Volume}}{\text{Rate}} \times \frac{\text{Drops per ml}}{\text{60 (minutes per hour)}}$

600 ml of fluid is dripping at 20 drops/min. The intravenous (IV) set delivers 15 drops/ml. How long will the infusion take?

$\frac{\text{Volume}}{\text{Rate}} \times \frac{\text{Drops per ml}}{60} = \frac{600}{20} \times \frac{15}{60} =$ 7 hours 30 minutes

QUESTION

Question 1.5 **An IV set delivers 15 drops/ml. A patient is to receive 1 l of Intralipid at 30 drops/min. How long will the infusion take?**

TOP TIP

0.33 does not mean 0.33 minute. This is a decimal value and needs to be changed to minutes by doing the following conversion:

$$\frac{33}{100} \times 60 \,(\text{minutes per hour}) = 19.8 = \sim 20 \text{ minutes}$$

Drugs According to Body Weight

$$\text{Formula : Total dose per day} = \text{Weight (kg)} \times \text{Dose}$$

A patient with diabetic ketoacidosis needs to commence a fixed rate insulin infusion at 0.1 unit/kg/h as per trust policy. How much insulin should be prescribed to an 85 kg patient?

$$\text{Weight} \times \text{Dose} = 85 \times 0.1 = 8.5 \text{ units / h}$$

QUESTION

Question 1.6 **A patient has a deep vein thrombosis and has been prescribed enoxaparin (low-molecular-weight heparin). The patient weighs 74 kg. The dose of enoxaparin is 1.5 mg/kg. How much do you administer?**

DID YOU KNOW?

I think my calculator is broken. The only numbers that seem to work are 1, 3, 5, 7, and 9. It's very odd.

Calculating How Many Minutes Drug to Run Over

Formula: $\dfrac{\text{Dose prescribed}}{\text{Rate}}$

Furosemide should not exceed 4 mg of the run over one minute because of speed shock. A patient has been prescribed 20 mg. Over what time should this be administered?

$$\frac{\text{Dose prescribed}}{\text{Rate}} = \frac{20}{4} = 5 \text{ minutes}$$

GLOSSARY

Speed shock

A systemic reaction caused by the rapid injection of a medication into the circulation, resulting in toxic levels of medication in the plasma. Symptoms can include cardiac arrest, flushed face, headache, irregular pulse, shock fainting, and tightness in the chest.

QUESTION

Question 1.7 A patient has been prescribed 15 mg. Over what time should this be administered?

Percentage Strength of Drug

A patient is given 2 l of 0.45% sodium chloride. How many grams of sodium will the patient receive?

Change 2 l into millilitres = 2000 ml.

$$\frac{2000}{100} \times 0.45 = 9 \text{ g}$$

QUESTION

Question 1.8 How many grams of medication do you have in 20 g of 12% w/w ointment?

Solution Strength of Drug (mg/ml)

500 mg of amoxicillin powder has been reconstituted in 25 ml of water for injection. What is the concentration in milligrams per millilitre (mg/ml)?

$$\frac{500}{25} = 20\text{mg / ml}$$

QUESTION

Question 1.9 **1 g of a drug has been reconstituted in 20 ml of water for injection. What is the strength in mg/ml.**

Extra Questions

And now a couple of questions for you to do on your own – just for your own enjoyment!

QUESTION

Question 1.10 **A patient is given 0.9% sodium chloride at a rate of 400 ml/h for five hours. How many litres will the patient receive?**

QUESTION

Question 1.11 **An infusion of dextrose 5% started at 10:00 and finished at 22:00. How many litres will the patient have received if the infusion is running at a rate of 100 ml/h?**

QUESTION

Question 1.12 **A patient has been prescribed ibuprofen 5 mg/kg/d in three divided doses. The patient weighs 60 kg. Calculate the daily dose and single dose.**

DID YOU KNOW?

OD = Once daily
BD = Twice daily, or 12 hourly
TDS = Three times daily, or 8 hourly
QDS = Four times daily, or 6 hourly

QUESTION

Question 1.13 Stock ampoules of IV hydrocortisone = 100 mg in 2 ml. Patient requires 135 mg IV. How much would you administer?

QUESTION

Question 1.14 A patient is to have 2 l of clear fluid in 24 hours. He has received 1500 ml in 6 hours. How many drops per minute are required to correct the infusion?

TOP TIP

If you struggled with any of these calculations, perhaps you may wish to read the calculations book in this student survival series set of books.

Now let's look at some advanced body, organ, and systems calculations starting with infant feeding regimens.

CALCULATING INFANT FEEDING REGIMENS

Obviously, correctly preparing feeds for bottle-fed babies is important. A hungry baby usually cries between feeds, and an overfed baby can experience diarrhoea and vomiting.

Infants need to receive 150–200 ml per kilogram body weight per 24 hours. Here is the formula for calculating feed:

$$\text{Volume of feed} = \text{Amount of milk (ml)} / \text{Number of feeds in 24 hours} \times \text{Weight of baby (kg)}$$

Activity 1.2

ACTIVITY

Calculate the volume of feed for a baby weighing 4.9 kg. He is fed six times every 24 hours. Remember that you need to calculate for the least (150 ml) and the most (200 ml) amounts.

WORKING OUT INFANT GROWTH EXPECTATIONS

A newborn baby is expected to regain birth weight after two weeks and then gain the following:

200 g per week until three months of age
150 g per week for a further three months
100 g per week until nine months of age

Three months is assumed to equal 13 weeks.

Imagine that you are required to calculate the expected weight of an infant aged 12 weeks whose birth weight was 3.2 kg. After two weeks, this infant weighs 3.2 kg again. The answer is:

$12 - 2 = 10$ weeks
At 200 g/week $= 10 \times 200$ g $= 2000$ g $= 2$ kg

Therefore, the expected weight $= 3.2$ kg $+ 2$ kg $= 5.2$ kg at 12 weeks old.

ACTIVITY

Activity 1.3

You are required to calculate the expected weight of an infant aged 12 weeks whose birth weight was 2.2 kg. After two weeks, this infant weighs 2.2 kg again.

BODY SURFACE AREA ESTIMATIONS

For neonates and children, body surface area (BSA) estimates are more accurate than body weight when calculating drug dosages.

As people grow in height and weight, their skin surface area increases – this BSA is measured in square metres (m^2).

The most commonly used simplified formula to determine BSA is the Mosteller formula, which is expressed as:

Body surface area: the square root of product of the weight in kilograms multiplied by the height in centimetres divided by 3600. The result is in square metres.

Or how I express this:

$$\text{BSA}\left(\text{m}^2\right) = \sqrt{\frac{\text{height}\left(\text{cm}\right) \times \text{weight}\left(\text{kg}\right)}{3600}}$$

Then, to calculate BSA using this formula, I get my calculator: I put in the height (or length) of the child in centimetres and multiply it by the weight of the child in kilograms. I then divide the result by 3600 (do not worry about where the 3600 comes from, just go with it). When I have an answer, I press the square root button on my calculator to get the BSA in square metres (m^2).

Here is an example that walks you through the steps.

Your first patient of the day is a woman 1.70 m tall and weighing 65 kg – you need to calculate her BSA:

1. **Convert metres into centimetres.**

   $1 \text{ metre} = 100 \text{ centimetres, and so}$
   $1.70 \times 100 = 170 \text{ centimetres}$

2. **Multiple height by weight.**

   $170 \times 65 = 11{,}050$

3. **Divide the result in step 2 (11 050) by 3600.**

   3.0694

4. **Find the square root using a calculator.**

   1.75 m^2

Activity 1.4

You need to find the BSA of a small child weighing 16.4 kg whose height is 100 cm.

However, many people use a scale called a *nomogram* to estimate BSA, although it is considered to be much less accurate that the Mosteller formula. There are separate nomograms for infants, children, and adults. Figure 1.2 shows the nomogram for infants for working out the BSA.

Let me show you how to use the nomogram. First, get a ruler or something with a straight edge. If you want to find the BSA of an infant with a length of 70 cm and a weight of 32 kg, place the straight edge on the height scale at 70 cm and across to the weight scale at 32 kg. The straight edge crosses the surface area scale at approximately 0.78. This means that the BSA is 0.78 m^2. Try this out for yourself on the nomogram.

Now, put the same details into the Mosteller formula:

$$\frac{\text{Height} \times \text{weight}}{3600} = \frac{70 \text{ cm} \times 32 \text{ kg}}{3600} =$$

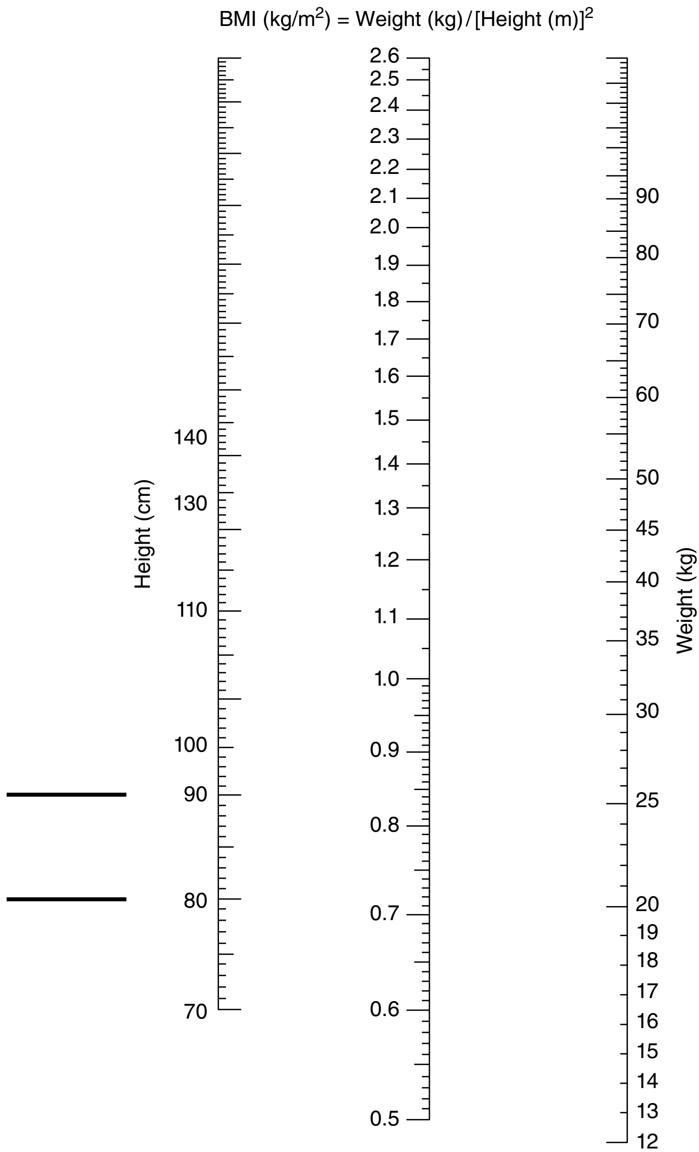

Figure 1.2 Nomogram for infants.

Using your calculator, input:

$$70 \times 32 = 2240 / 3600 = 0.62$$

Then find the square root, or press the square root button on your calculator, and you get 0.79 m^2.

The formula method and the nomogram method often give variable answers!

Table 1.1 shows some useful parameters of average values when administering medications to children, which should be used only if you are unable to find specific doses. **NOTE:** You will always need to check this first with the prescriber.

Table 1.1 Useful approximate values.

Age	Weight (kg)	Height (cm)	Surface area (m^2)	Percentage of adult dose
Newborn	3.4	50	0.23	12.5
1 month	4.2	55	0.26	14.5
2 months	4.4	51	0.28	15
3 months	5.6	59	0.32	18
4 months	6.5	62	0.36	20
6 months	7.7	67	0.40	22
8 months	8.5	72	0.44	25
1 year	10	76	0.47	28
18 months	11	90	0.53	30
3 years	14	94	0.62	33
5 years	18	108	0.73	40
7 years	23	120	0.88	50
10 years	30	142	1.09	60
12 years	37	145	1.25	75
14 years	45	150	1.38	80
16 years	58	168	1.65	90
Adult (male)	68	173	1.80	
Adult (female)	56	163	1.60	

BODY MASS INDEX

The body mass index (BMI) is the most commonly used measurement of obesity, but it is also used to check that individuals are within a healthy range. A high BMI is associated with an increased risk for ill health, such as cardiovascular disease.

The following is the formula for working out someone's BMI:

$$\text{BMI}\left(\text{kg} / \text{m2}\right) = \text{Weight}\left(\text{kg}\right) / \text{Height}\left(\text{m}\right)\text{2}.$$

The World Health Organisation classifies weight into BMI ranges (see Table 1.2).

Table 1.2 World Health Organisation weight classifications.

Description	Body mass index range (mmHg)
Normal	18.5–24.9
Overweight	25.0–29.9
Obesity Class I (moderate)	30.0–34.9
Obesity Class II (severe)	35.0–39.9
Obesity Class III (very severe)	>40.0

Activity 1.5

ACTIVITY

Robert Simons is a student nurse. His height is 1.72 m and he weighs 66 kg. Work out his BMI using the formula and his weight classification according to the World Health Organisation.

MAKING ORGAN AND SYSTEMS CALCULATIONS

Some of the calculations you need to perform in the healthcare setting are in relation to the bodily organs and systems, such as cardiac output (CO) measurements, lung function, and renal clearance measurements, to establish how healthy, or poorly, your patients are. This section looks at the calculations and formulae used to gather this information.

MEASURING CARDIAC OUTPUT

CO is the amount of blood pumped by the heart's left ventricle (in millilitres) in one minute (expressed as ml/min). It is dependent on the amount of blood pumped out with each ventricle contraction – known as the *stroke volume* (SV) – and the heart rate (also known as the *pulse rate* [P]). The SV at rest in the standing position averages between 60 and 80 ml of blood in most adults.

Here are some of the factors that increase CO:

- Anaemia
- Cirrhosis of the liver
- Pregnancy
- Severe infection
- Thiamine deficiency (beriberi)

To work out the CO, you can use the following formula:

$$\text{CO} = \text{SV} \times \text{beats per minutes}\ (\text{P})$$

This formula is often expressed as CO = SV × P = ml/min.

Given the SV and Ps shown in the following list, the resulting COs are as follows:

SV = 70 ml, P = 70 beats/min: CO = 70 × 70 = 4900 ml/min
SV = 69 ml, P = 65 beats/min: CO = 69 × 65 = 4485 ml/min
SV = 70 ml, P = 60 beats/min: CO = 70 × 60 = 4200 ml/min
SV = 65 ml, P = 62 beats/min: CO = 65 × 62 = 4030 ml/min

ASSESSING LUNG FUNCTION

Pulmonary function tests are important tests used in the evaluation of respiratory health. They are conducted for the following reasons:

- To screen for the presence of obstructive and/or restrictive lung diseases
- To evaluate the ability of a patient to be weaned off a ventilator
- To assess the progression of lung disease and the effectiveness of treatment
- To collect baseline readings before surgery to determine the risk for respiratory complications after surgery

In the respiratory world, you need to know the following terms:

Vital capacity: the amount of air that can be forcibly exhaled from the lungs after a full inhalation.

Forced vital capacity (FVC): the amount of air forcibly exhaled from the lungs after taking the deepest breath possible.

Forced expiratory volume in one second (FEV_1): the amount of air that can be forcibly exhaled from the lungs in the first second of a forced exhalation.

To assess the lung function, you use the following formula, which expresses it as a percentage:

$$\text{The expired volume ratio} = (FEV_1 \times 100\%) / FVC$$

Here's the process for calculating a person's total FVC when their FEV_1 is 4.5l and their FEV_1% is 90%:

$FEV_1\% = FEV_1 \times 100\% / FVC$

$90\% = 4.5\,l \times {}^{100\%/}90 = 4.5\,l \times {}^{100/}FVC$

$= 9 = 4.5\,l \times {}^{10/}FVC$

$FVC = 9 = 45^{1/}FVC$

$FVC = {}^{45/}\ 9 = 5$

Therefore, this person has a FVC of 5.0 l.

Now, you need to calculate the FEV_1% for an individual with a FEV_1 of 4.2 l and a FVC of 5.0 l:

$$FEV_1\% = 4.2 \times 100\% / FVC_1 \; 4.2 / 5.0 \times 100\% / 1$$
$$= 84\% FEV_1$$

RENAL CLEARANCE

Renal clearance refers to the ability of the kidneys to remove a given substance from the blood in a given time. Here's the formula for calculating the renal clearance:

$$\textbf{Renal clearance} = (\textbf{Urine} \times \textbf{Volume}) / \textbf{Plasma}$$

You can express this as $U \times V/P$.

Note that U = the concentration of the substance in the urine (mg/ml); P = the concentration of the substance in the plasma (mg/ml); and V = the volume of urine excreted (ml/min).

John Smith has the following recordings (in addition to all The Beatles albums!): U = 80 mg/ml, V = 120 ml/min, and P = 55 mg/ml. Here's how you calculate John's renal clearance of creatinine:

$$80 \times 120 / 55 = 174.5 \text{ ml / min}$$

WORKING OUT THE ENERGY REQUIREMENTS OF THE BODY

Energy calculations are generally performed by physicians and dieticians, but nurses can be asked to participate in the calculations when completing nutrition charts for patients.

Energy is measured in kilojoules (kJ). A calorie is a unit that indicates a food's energy value: 1 cal is equal to 1000 kcal (kcal) and 1 kcal = 4.2 kJ.

The average person should derive their energy sources from the following:

- 15% from protein
- 35% from fat
- 50% from carbohydrate

If a 35-year-old postal worker requires 3000 kcal/day, how many of these 3000 kcal should come from fat?

$$3000 \times 35\% = 3000 \times 35 / 100 = 1050 \text{ kcal}$$

To convert this amount into kilojoules: $1050 \times 4.2 = 4410$ kJ

A keen jogger has an energy requirement of 250 kJ/kg of body weight per day. If they weigh 50 kg, how many kilocalories do they require in one day?

$$250 \times 50 = 12\,500 \text{ kJ / day}$$

Converted in kilocalories = 12 500 kJ $\div$ 4.2 = 2976 kcal per day

Here's another little puzzle to keep your grey cells ticking over.

A patient is on a strict low-sodium diet totaling 2400 cal/day. The dietician asks you what his estimated caloric intake is for the day.

Find the answer as follows:

- **Look at the nutrition chart:** You see that they ate only 50% of their breakfast, lunch, and tea.
- **Work out the answer by multiplying the desired intake of 2400 cal by the percentage the patient consumed: 2400 kcal × 50%.**

Or more clearly: 2400 kcal $\times 0.5 = 1200$ kcal (the number of calories the patient has consumed today).

TEST YOUR KNOWLEDGE

1. A patient is prescribed 27 mg of Adenocor. Stock ampoules contain 30 mg in 10 ml. What volume of the drug do you need to administer?
2. What is the BSA for a small child weighing 18.2 kg and with a height of 110 cm?
3. What is the BMI for a woman with a height of 1.55 m and a weight of 120 kg?

4 Find the CO from the following readings: SV = 75 ml.

5 Solumedrol 2.5 mg/kg is prescribed for a child weighing 15 kg. Stock ampoules contain 125 mg/3 ml. How many millilitres do you administer?

6 Work out the renal clearance of a patient with the following readings:
Urine: 50 mg/ml
Volume: 20 ml/min
Plasma: 40 mg/ml

KEY POINTS

- MAP
- Revision of drug administrations
- Percentage strength of drug
- Solution strength of drug (mg/ml)
- Infant feeding regimens
- Infant growth expectations
- BSA
- BMI
- Measuring CO
- Assessing lung function
- Renal clearance
- Working out energy requirements of the body

WEB RESOURCES

BMI: https://www.nhs.uk/common-health-questions/lifestyle/what-is-the-body-mass-index-bmi/
Nutrition: https://www.nutrition.org.uk/
World Health Organisation BMI: https://www.who.int/toolkits/child-growth-standards/standards/body-mass-index-for-age-bmi-for-age
Maths: http://bbc.co.uk/schools/gcsebitesize/maths/number
Healthcare math: https://www.mathcentre.ac.uk/students.php/health/arthmetric/rules/resources/
Maths: https://testandcalc.com/
Healthcare math: www.snap.nhs.uk