# 4.

# USCOM – What the numbers mean

## A guide for Nursing and Junior Medical Staff


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# Introduction.

So now you can do an USCOM examination and get a good tracing, and from books one and two, you'll have some idea of what the numbers are about, although learning what they mean is as much about practicing their application with real clinical cases as it is about understanding the theory. When you first started using the numbers at the bedside, you probably started with just cardiac output. It probably wasn't long before you started looking at three or four other indices that you were confident with, to see how they changed and interacted with your interventions and the patient's clinical course. The most common (and simple) framework is usually to start off looking at Cardiac Output (CO) (or Cardiac Index (CI)), Stroke Volume (SV) and SVR. If you've read book 3, "The USCOM and Inotropy" then you are probably looking a lot more at FTc.

For example, an adult patient in **septic shock** will usually have a low SVR, and a high CI, depending on how well preloaded they are. Since they usually need fluid, the SV and FTc are usually low. Watch what happens as you fill them with fluid; their SV and FTc increases, and as SV is raised CI increases also. Once they are adequately preloaded their FTc will be normal, but they may remain hypotensive, despite a high CI, because the SVR is low. Once you start the noradrenaline, you see the SVR increase, and you appreciate how nice it is to have indices to titrate your treatment against.

Similarly, you could look at a patient with **cardiogenic shock** using the four simple indices of CO/CI, SV/SVI, SVR and FTc. The CI is low resulting in a low blood pressure, and the body compensates to maintain perfusion by raising SVR. The FTc will probably be normal to high, warning you that extra fluid (preload) won't help you here. Similarly the SV is likely to be low, but attempting to increase it further with fluid won't raise the CI because the Starling curve is too flat (or even dipping). However when you start an inotrope, such as dobutamine, the CI increases, and the body responds by reducing the SVR. Again it is nice to understand the effect of therapy by measuring these simple haemodynamic parameters

Measuring these basic indices in real patients, simplifies clinical decision making and allows an appreciation of how easy circulatory management can be when you have real time objective information at your fingertips. Although we learnt these numbers at university, we by-passed them as there was no method of acquiring this information in clinical practice. It's nice to welcome our old friends back! Once you're comfortable using these basic numbers in clinical situations, it's time to expand your repertoire and further eliminate the clinical guesswork. It's time to read on…..

# The Haemodynamic Jigsaw!

In haemodynamics, everything is inter-related like cogs in a machine or the pieces of a jigsaw puzzle. Its only when you put all the pieces together that you see the full picture. Looking at a single piece in the puzzle, say CO, will tell you very little about what's really going on and what needs to be done. Putting three or four key pieces together will improve our understanding. Can we put eight or more pieces into the puzzle required for a more complete understanding? Yes we can, but it becomes more complex and we need to develop a systematic and methodical way of looking at the data to allow piecing the big picture together. So where do we start?

**Peripheral Demand not Central Supply.**

Perhaps the first thing we need to understand is that the heart is not the leader or the primary controller of the circulation, it is just the pump. It is the consumer of electricity not the power station that determines electricity flow. When you flick the switch on your wall the current flows. How much current flows depends on how many switches you flick. It is a consumer-led economy! Haemodynamics is similar. The peripheral circulation dilates or constricts in response to the metabolic needs of the cells. It's the circulation that flicks the switches, and the heart responds.

Generally it is the cells need for oxygen that determines the vessels tone. If a tissue needs more oxygen, then it stimulates regional vasodilation to increase the blood flow and thereby regional oxygen delivery. This vasodilation reduces the SVR. Consequently the SV increases because the afterload has reduced, and the ventricle can empty more easily. In normal health the ventricle only produces an SV of about ⅔ of the ventricular end diastolic volume, an ejection fraction of about 66%. This gives the heart some leeway to increase or decrease the SV to meet the beat to beat variations in preload and afterload.

This is an entirely mechanical effect, and doesn't require the sympathetic system to intervene. As we know $CO = SV \times HR$, so small variations in SVR "automatically" change SV and thus CO. If SVR decreases then SV increases, and CO rises, so from $BP = CO \times SVR$, the BP is maintained at the normal level.

**The Sympathetic System.**

But what if it is not just a minor reduction in vascular tone or is not restricted to one region? In this case the fall in SVR is greater than a simple passive increase in SV can compensate for, and a further increase in flow is required by the tissues. This is when the sympathetic system kicks in.

Increased sympathetic system activity leads to an increase in heart rate (HR) and an increase in inotropy, which increases SV. (see booklet 3, "The USCOM and Inotropy") The increased CO brings BP back up to normal, and the tissues get the increased blood flow that they have asked for; simple but crucial! The leader in this process is clearly the tissues, the heart and the sympathetic system were just responding to their demands.

This basic appreciation of how the tissues need for oxygen and blood flow is the main regulator of the circulation is absolutely central to understanding haemodynamics. Ask yourself ***"what is the body asking for?"*** Put yourself in the position of the body and see if you can understand its demands on the heart and the circulation.

**Where do we start?**

It might seem logical to start with CO, but do you know the normal CO for every size and age of patient that you see? No, I didn't think so. So would CI be better? Well again, what's the normal CI for a 60kg woman of 70 years of age? How about a 7 year old boy of 24Kg? The normal CI varies considerably with age, weight, height, body shape, normal levels of physical activity and around the times of growth spurts. Could our simple model of peripheral demand leading central supply help us here? Perhaps SVR would be a better starting point. In adults this might have merit, but the SVR is size dependant. Just look at the SVR of an infant and you'll see what I mean; an SVR of 2000+ might seem high until you realise that a small child has far less tissue (and therefore "less taps to turn on" – see below) than an 80kg adult. Even SVRI varies enormously with age, height and weight.

So is there anything which applies across the board from infants to octogenarians? Fortunately there is, the Minute Distance (MD).

**Minute Distance.**

Unless you're familiar with echocardiography, the concept of MD will be alien to you. Technically it is how far a single red blood cell travels in one minute, OK so that's clear as mud then! But in effect, it's the mean aortic valve flow velocity (or pulmonary valve flow velocity if you're looking at the right side of the heart) and technically is the area under the ejection curve, the velocity-time integral, Vti, multiplied by HR.

Imagine the main water pipe coming from the reservoir to a town, the more water that is being used by the consumers, the higher the velocity of flow there must be in the pipeline. On a hot day when everyone is using the shower or

filling their pool, the velocity of flow in the pipeline will be very high. At two in the morning on the other hand, the flow velocity will be very low because the consumers have all the taps turned off. The body is just the same, when the taps are all turned on, i.e. the tissues are demanding a lot of blood, the flow velocity in the aorta will be high, a high MD. The normal MD is 14 – 22 in adults, and just a little higher at 16 – 28 in kids.

OK, so a high MD equals a high demand, and a low MD presumably means a low demand. Well not so fast there. Let's go back to the reservoir and the pipeline. What would happen if the pump was failing and couldn't keep up with demand? Obviously, the flow velocity in the pipeline would fall. What if the water level in the reservoir was very low or the water intake to the pump was blocked? Again, a low flow velocity. So a low MD doesn't necessarily mean a low demand. It could also mean that there was a problem with the pump or inadequate preload, or even a pulmonary embolus blocking the intake for the pump. Get the idea?

A low MD just might mean that the tissues are not asking for much blood, but unless you've just done an USCOM on a hypothermic patient (or on a hibernating bear!) this is not very likely. A low MD is nearly always pathological and points back at the pump or the reservoir as the cause. On the other hand, a high MD either means that the body is demanding high delivery of oxygen, as in strenuous exercise, or that some pathological process is causing excessive vasodilation as in sepsis.

The MD immediately tells us whether the circulation is normodynamic (normal flow velocity and normal MD), hypodynamic (low flow velocity and low MD) or hyperdynamic (high flow velocity and high MD).

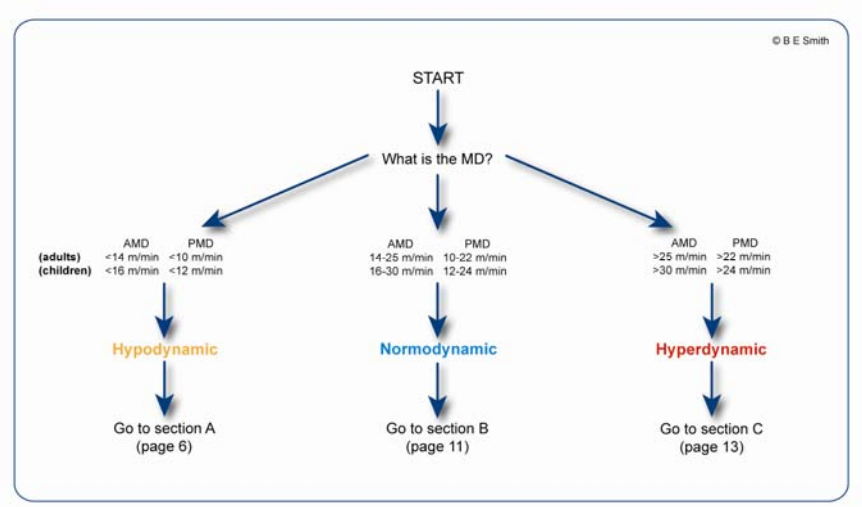
**High, Low or Normal MD?**

1) Normodynamic (14–22m/min). If the MD is normal then the circulation is normodynamic and it is unlikely that there will be any major abnormality of haemodynamics or any major abnormality in the USCOM parameters. It does not however exclude minor or subtle abnormalities that have been compensated for within normal haemodynamic controls.

2) Hypodynamic (<14m/min). The MD will be below 14m/min. This is usually due to inadequate venous return to the left atrium due to hypovolaemia, haemorrhage or even a pulmonary embolus, or cardiac failure. The body will be demanding more blood but it's either not there to be delivered or the pump is failing and can't deliver it.

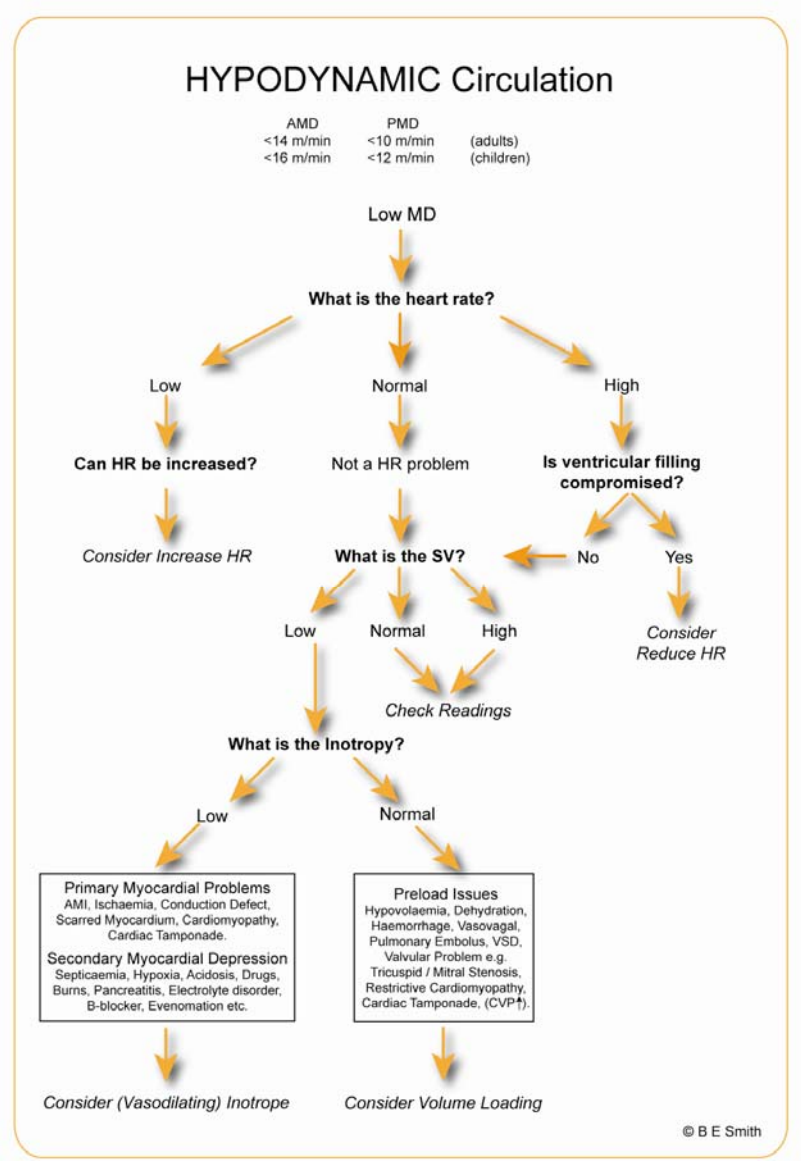
3) Hyperdynamic (>22m/min). The body is asking for a higher blood flow than normal so we need to ask why this is. A good example of this is during exercise. The body is burning oxygen at an increased rate so it needs a higher blood flow to deliver it. It could also be pathological however, as in cytotoxic hypoxia. The tissues are calling for more oxygen even though there is plenty being delivered by the circulation. The problem is that the tissues can't use it.

So from this simple starting point, we can devise a decision tree that will guide us through the maze of haemodynamics allowing us to put all the pieces together? Well let's try it.



## Section A - Hypodynamic Circulation.

Now using the USCOM we can identify more exactly where the problem lies. Why is the MD low (<14m/minute)?



In this way the hypodynamic circulation can be reduced to just two problems – assuming HR is not the problem –

1. Insufficient preload or ventricular filling,
2. Pump Failure.

Hypodynamic circulation means we should be looking at the circulation *before* the aortic valve. A hyperdynamic circulation is very different as we will see in section C.

## Hypertension.

There is one very important exception to this rule; hypertension due to a high SVR - vasogenic hypertension. As BP = CO x SVR, hypertension can be caused by either a high CO, a high SVR or a combination of the two. If the SVR is high, then the heart may be unable to maintain a normal CO against the high afterload and the MD will consequently fall. On the other hand, in cardiogenic hypertension the high CO will lead to an increased MD. Again, MD gives us an instant reference value to identify the cause of the hypertension. We can then confirm and quantify the problem from the USCOM values.

## Inotropy.

This also shows the importance of inotropy measurement in making sense of a reduced SV. The SV could be low because the preload is low, the afterload is very high or it could be due to low cardiac inotropy. If the SVR is over 1600 then we have an afterload issue. If the FTc, SVV and LVEDVI all suggest that the preloading is OK but the Smith-Madigan Inotropy Index (SMII) is only 0.9W/$m^2$, then we are looking at cardiac failure. The decision to use an inotrope then becomes very easy.

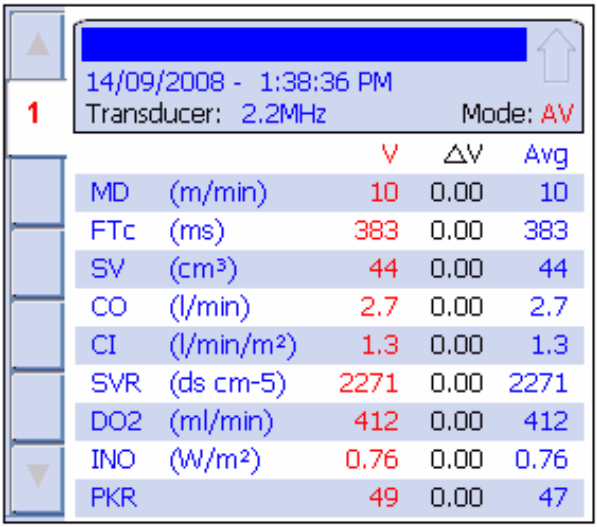
On the other hand if the SMII is 1.4 W/$m^2$ and the FTc and LVEDVI look to be low whilst the SVV is high, then this is almost certainly a preload problem. A passive leg lift test should clarify the position. (See booklet 3 "The USCOM and Inotropy" for the details of the passive leg lift test.)

However, you might say that an SMII of 1.4 W/$m^2$ is a bit low. Yes it is, but inotropy responds to preload, so if we increase ventricular filling then we stretch the cardiac muscle fibres a little more which increases the force of contraction, as Starling explained. If preload is low then ventricular stretching, and consequently inotropy is reduced. A slightly low SMII is therefore typical in low preload states. We see a similar situation in cardiac tamponade where the ventricle is not allowed to fill properly and the cardiac myofibrils are not

pre-stretched. Not only will SV be low, but so too will be SMII, and may be very low (<1.0W/$m^2$) in symptomatic patients.

So a hypodynamic circulation that is not due to either a tachyarrythmia or bradycardia either needs preload increase, afterload reduction or an increased inotropy, or a combination of these. Now, that makes sense!

Take a look at the data below. The MD is just 10 m/min; a hypodynamic circulation. Can you explain why this is, and also how to treat this 57 year old 76 Kg male patient? His BP is 106/64 (MAP - 76mmHg).



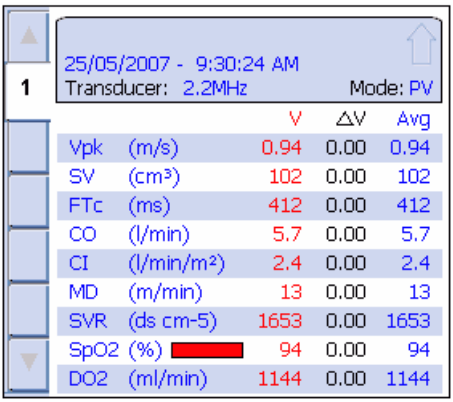

| | | V | ΔV | Avg |
|---|---|---|---|---|
| MD | (m/min) | 10 | 0.00 | 10 |
| FTc | (ms) | 383 | 0.00 | 383 |
| SV | (cm³) | 44 | 0.00 | 44 |
| CO | (l/min) | 2.7 | 0.00 | 2.7 |
| CI | (l/min/m²) | 1.3 | 0.00 | 1.3 |
| SVR | (ds cm-5) | 2271 | 0.00 | 2271 |
| DO2 | (ml/min) | 412 | 0.00 | 412 |
| INO | (W/m²) | 0.76 | 0.00 | 0.76 |
| PKR | | 49 | 0.00 | 47 |

The MD is low, the SV is low, CO and CI are low. His $DO_2$ is also low, we would expect around 12–15 ml/kg/min or around 912–1,140 ml/minute in this patient. The FTc at 383 is about normal which suggests that this is not a preload issue. The SVR is high, which could be primary or could be secondary to the low CO, i.e. he is vasoconstricting to try to maintain blood pressure. Given that his MAP is just 76mmHg, this doesn't look much like vasogenic hypertension! The SVR must therefore be secondary compensation for the low CO. The SMII (or "INO" on the USCOM screen) is only 0.76 W/$m^2$. This is typical of myocardial failure, which was treated with dobutamine, to increase the SMII and CO and lower the SVR! Now that was easy!

But there's more. We said his $DO_2$ needs to be increased to around 1,000 ml/minute. His cardiac index is only 1.3 l/min/$m^2$. If we doubled his CO to a more normal level (a CI of 2.6 l/min/$m^2$) his $DO_2$ would only increase to 824 ml/minute. There must be something else going on.

Now we know that $DO_2$ = 1.34 x Hb x CO x $SaO_2$% so either this man has a low haemoglobin (Hb) or a low $SaO_2$. So which is more likely? If you are using an Oxycom (USCOM with built in pulse oximetry) then the answer is obvious. His $SpO_2$ was only 84%. Increasing his CI to 2.6 l/min/$m^2$ and his $SpO_2$ to 100% would give us a $DO_2$ of about 980 ml/minute – close enough!

Sometimes the initial USCOM values might be on the edge of normal. It is always worth reviewing these in more detail. You'd be surprised what this may reveal. Below are the initial USCOM measures from a 47 years old male weighing 89kg with a BP of 144/86 (MAP-105mmHg). He complains "I just have no energy and I'm always tired".




| | | V | ΔV | Avg |
|---|---|---|---|---|
| Vpk | (m/s) | 0.94 | 0.00 | 0.94 |
| SV | (cm³) | 102 | 0.00 | 102 |
| FTc | (ms) | 412 | 0.00 | 412 |
| CO | (l/min) | 5.7 | 0.00 | 5.7 |
| CI | (l/min/m²) | 2.4 | 0.00 | 2.4 |
| MD | (m/min) | 13 | 0.00 | 13 |
| SVR | (ds cm-5) | 1653 | 0.00 | 1653 |
| SpO2 | (%) | 94 | 0.00 | 94 |
| DO2 | (ml/min) | 1144 | 0.00 | 1144 |

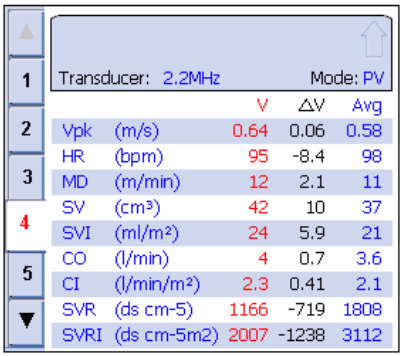
If you follow the algorithm then you'll see that this man is borderline hypodynamic. The next question according to the algorithm is "What is the heart rate?" You haven't been given this, but you can work it out from his SV and CO (5,700ml/102ml). In fact it is 56/minute. Does that give you any clues? His SVR is rather high for a man of his age and his $SpO_2$, measured from a finger probe, is apparently low at just 94%. Got it yet?

Well something is giving him a bradycardia, is increasing his SVR and maybe giving him vasoconstricted fingers as well. You know his BP is elevated. Could this be iatrogenic? The answer is yes, he's being treated with the β blocker drug atenolol. His CI is right on the edge of cardiac failure which is why he feels tired. But what can be done about it?

He clearly needs an increase in his CO, but if his SVR were to stay at 1650 the increase in his CO would also increase his BP. Therefore his SVR needs to be reduced and his CO increased at the same time, thereby reducing his BP from the current level of 144/86. The answer of course is to switch him over from atenolol to a peripheral vasodilator.

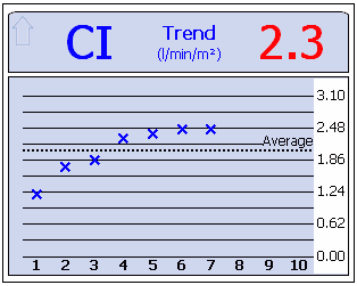
This patient was slowly withdrawn from atenolol and commenced on an ACE inhibitor. His BP reduced to 132/76 (MAP-95mmHg), his pulse increased to 74/minute and his CI rose to 3.2 l/min/$m^2$. His SVR fell to 1124. More importantly he reported feeling "better than I've felt for ages!" Well, that's no big surprise when you understand the haemodynamics!

On the other hand, this 68 year old female of 63Kg was being treated as an outpatient for chronic heart failure. Are there any pieces of the jigsaw that you feel are missing? What other indices would help you to understand this?




| | | V | ΔV | Avg |
|---|---|---|---|---|
| Vpk | (m/s) | 0.64 | 0.06 | 0.58 |
| HR | (bpm) | 95 | -8.4 | 98 |
| MD | (m/min) | 12 | 2.1 | 11 |
| SV | (cm³) | 42 | 10 | 37 |
| SVI | (ml/m²) | 24 | 5.9 | 21 |
| CO | (l/min) | 4 | 0.7 | 3.6 |
| CI | (l/min/m²) | 2.3 | 0.41 | 2.1 |
| SVR | (ds cm-5) | 1166 | -719 | 1808 |
| SVRI | (ds cm-5m2) | 2007 | -1238 | 3112 |

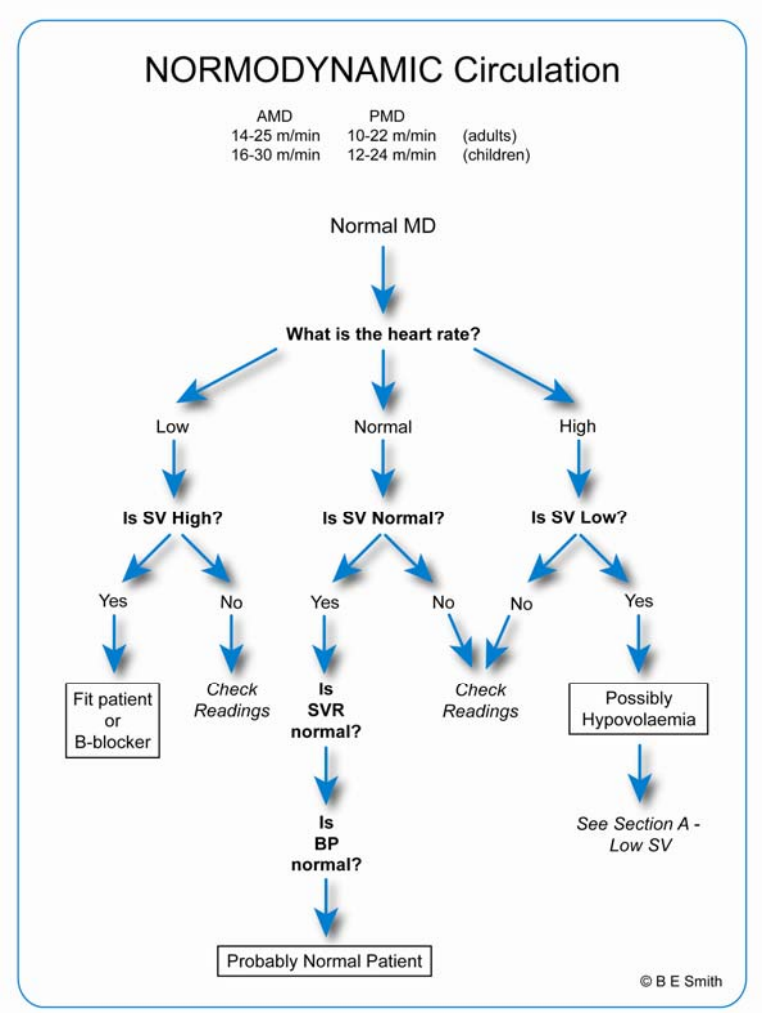
If you answered "what is the SMII and what is her FTc" then you're ready to move on to the next section, but before we do you might just like to see what her cardiac index had been doing over the previous 8 weeks that she had been coming to the hospital....



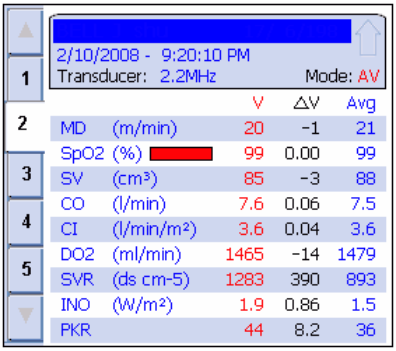

A CI of 2.46 might not seem that great, but it is significantly better than the 1.22 L/min/$m^2$ of her initial presentation; a 101% improvement in CI! Reading 2 was taken after she started a diuretic, reading 3 after she commenced on digoxin, and reading 4 after an ACE inhibitor was added. Logical therapy without guesswork.

## Section B - Normodynamic Circulation.

The MD is between 14 and 22 m/minute (16-28 in a child). As a general rule, if the circulation is normodynamic then it is unlikely that there will be any major circulatory disturbance. Minor abnormalities may be seen which usually show inherent compensation within the circulation. This occurs in minor degrees of volume depletion for example, where a small reduction in SV is compensated for by an equivalent rise in HR, keeping CO and perfusion within the normal range. MD will therefore be normal.



This is a 24 year old 78kg male, immediately prior to elective surgery, after fasting for almost 9 hours. Can you tell?




Initially this looks normal, but let's look at some of the detail.

His MD is normal at 20 m/min. His BSA is 1.76$m^2$, so why has he got a $DO_2$ of 1465 ml/min and a $DO_2I$ of 832ml/min/$m^2$ – almost 40% in excess of normal (600ml/min/$m^2$). His CI is a little high at 3.6 considering that he's lying in bed. You haven't been given his HR but it must be 7,600/83 or about 91/min. Maybe just up a little? His SV is 1.1ml/Kg. Is this just a little low? His SMII is in the middle of the normal range. The answer is revealed when we look at PKR. His PE:KE ratio is 44:1. In a fit young man of his age 25:1 or 30:1 would be more like it. He is slightly vasoconstricted, SVR of 1283. His BP was slightly high at 136/92 (MAP of 112mmHg).

So what does all this mean? This is a man who is anxious, presumably because he is going to have his hernia repaired within the hour. His SV is a little low and his HR, PKR, SMII and SVR are all a little high. Is this because he has had no fluid intake for the last 9 hours leaving him dry as well as anxious? It looks like it.

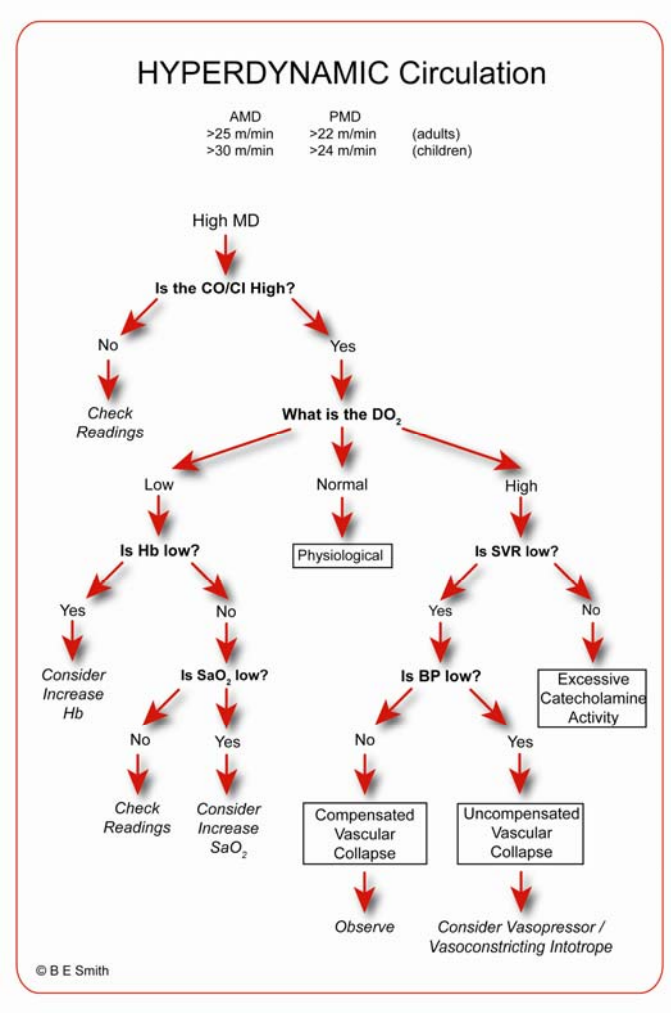
This is what I meant when I said that even in a normodynamic circulation there may be subtle compensations going on within the circulation. Haemodynamics can spot some surprisingly fine details!

Sometimes confirming that the circulation is normal is a very positive finding. If this man had been severely dehydrated and we had been volume replacing him, then these figures would show that we had almost achieved our goal. He probably just needs another litre of fluid and the numbers would all be close to normal. So normodynamic circulation is actually our end point or therapeutic goal in the treatment of any hyperdynamic or hypodynamic state. If the patient is normodynamic then we have "cured" them; if they're not, then we should continue with our therapy.

Ensuring normodynamic circulation before discharge would seem prudent, whilst abnormal measurements suggest further observation and treatment may be required. Before discharging a child from ED with what appears to be a non-specific febrile illness you might like to think about this!

## Section C - Hyperdynamic Circulation.

The most common cause of a hyperdynamic circulation is **anaemia**. If the haemoglobin concentration is low then the CO ***must*** increase to maintain oxygen delivery. If MD is >22 (28 in a child) then your first thought should be "what is the haemoglobin level?" There are also many physiological causes of a hyperdynamic circulation. Pregnancy, exercise, pain, fear and anxiety can all increase CO significantly, as well as pyrexia and hypercapnia. Could the high MD be due to one of these? If not, then let's analyse the USCOM readings.

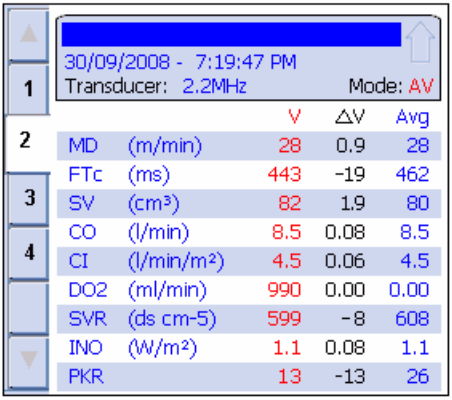


The most important question with hyperdynamic circulation is "what is the $DO_2$? If the circulation is truly hyperdynamic then almost invariably it is because the body is asking for more oxygen to be delivered.

If $DO_2I$ is high, (greater than 500ml/$m^2$/min) then we have a problem with oxygen uptake and utilisation, as in cytotoxic hypoxia, or there is a distributive problem, such as a shunt. A major fistula from the aorta to the vena cava (or multiple smaller fistulae) is an uncommon cause of this. If a hyperdynamic circulation is not due to anaemia, pyrexia, pregnancy, childhood or hypoxia / hypercapnia, then septicaemia must a critical consideration. An SVR of 600 can certainly be physiological, but 300 is almost certainly not! Look for pathological vasodilation as the cause of a high MD and high CO/CI. If $DO_2I$ is also high (>500ml/min/$m^2$) then its pathological till proven otherwise!

One word of caution. If the SVR is low, BP is low and the CO high, then we are looking at high CO failure (HOCF) by definition. I would refer you to booklet 3 in this series, "The USCOM and Inotropy", but beware of simple vasopressors! Very seldom is inotropy normal in this condition. A vasopressor may increase the SVR back to normal, but can the left ventricle cope with this increased afterload? If there is any significant myocardial depression then the answer is probably no. Noradrenaline (norepinephrine) may be a wiser choice, or even balanced inotropes (see booklet 3, "The USCOM and Inotropy").

This 27 years old 82 Kg female has pneumonia. BP = 86/45 (MAP-59mmHg). What do you see?




| | | V | ΔV | Avg |
|---|---|---|---|---|
| MD | (m/min) | 28 | 0.9 | 28 |
| FTc | (ms) | 443 | -19 | 462 |
| SV | (cm³) | 82 | 1.9 | 80 |
| CO | (l/min) | 8.5 | 0.08 | 8.5 |
| CI | (l/min/m²) | 4.5 | 0.06 | 4.5 |
| DO2 | (ml/min) | 990 | 0.00 | 0.00 |
| SVR | (ds cm-5) | 599 | -8 | 608 |
| INO | (W/m²) | 1.1 | 0.08 | 1.1 |
| PKR | | 13 | -13 | 26 |

Her MD is certainly raised at 28. We should therefore be thinking "what is the haemoglobin?" In this case it was 128g/litre, so anaemia is not the cause. According to the algorithm, the next question is "what is the $DO_2$?" We can see that the answer is 990 ml/minute, but is this high, normal or low? To answer this we need to know what the $DO_2I$ is. Now, you were not given this but it is

easy to work out. First we need the BSA. The CO is 8.5 L/min and the CI is 4.5 L/min/$m^2$. BSA must therefore be 8.5/4.5 or 1.88 $m^2$ as CI= CO/BSA. $DO_2I$ is thus 990/1.88 or 526 ml/$m^2$/min, above the normal level of 500ml/$m^2$/min.

According to the algorithm, the next question is "Is the haemoglobin low?", but we know that it isn't. The next question is "Is the $SaO_2$ low?" Now again you haven't been given this, but from $DO_2$ = 1.34 x Hb x CO x $SaO_2$/100, then if her Hb is 128 and her CO is 8.5 L/min, then if her $SaO_2$ were 100% then the $DO_2$ would work out as 1458 ml/min. Clearly her saturation is not 100%! In fact it must be 990/1458 or just 68%. So why is her circulation hyperdynamic? Easy – with a saturation that low, the CO has to be high to deliver enough oxygen to the tissues. But how did the heart know that? Well it didn't, unless you say that the SVR told it! The SVR has fallen to 599, indicating a marked degree of vasodilation. Her PKR at 13 also indicates this. The heart didn't know it, the tissues asked for it. With this degree of vasodilation it is not hard to see why she is hypotensive despite the high CO.

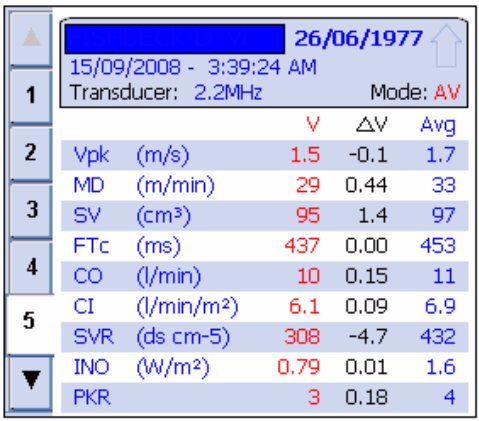
This example also illustrates how it is possible to calculate many of the parameters that you have not been given from those that you have. This shows the beautiful interlocking nature of all the variables in haemodynamics. You don't have to measure everything to understand everything! From the pieces of the jigsaw that you do have it is easy to see what the missing pieces are.

So what conditions result in a hyperdynamic circulation? Here's just a few!

| Oxygen Delivery Problems: | Cell nutrition problems: | Poisoning: |
|---|---|---|
| Anaemia,<br>Haemoglobinopathies,<br>Hypoxia (global),<br>Shift in $O_2$ dissociation curve,<br>2,3 DPG abnormalities,<br>Hypercarbia. | Hypoglycaemia,<br>Hypoxia,<br>Hypophosphataemia,<br>Vit B deficiency,<br>Thyrotoxicosis,<br>Malnutrition. | Septicaemia<br>Carbon monoxide,<br>Cyanide,<br>Evenomation,<br>MDMA / Amphetamines<br>Antihypertensives<br>Histamine releasers<br>(e.g. anaphylaxis) |

These lists don't include iatrogenic causes such as excessive vasodilator therapy with sodium nitroprusside, ACE inhibitors, frusemide or hydralazine. Did I mention heat stroke? Get the idea? Vasodilation is at the heart of a hyperdynamic circulation. The question we have to answer is simply – did the tissues ask for this much blood and oxygen or was it inappropriate (i.e. pathological) vasodilation?

Another example of hyperdynamic circulation; take a look at this set of USCOM data.




| | | V | ΔV | Avg |
|---|---|---|---|---|
| Vpk | (m/s) | 1.5 | -0.1 | 1.7 |
| MD | (m/min) | 29 | 0.44 | 33 |
| SV | (cm³) | 95 | 1.4 | 97 |
| FTc | (ms) | 437 | 0.00 | 453 |
| CO | (l/min) | 10 | 0.15 | 11 |
| CI | (l/min/m²) | 6.1 | 0.09 | 6.9 |
| SVR | (ds cm-5) | 308 | -4.7 | 432 |
| INO | (W/m²) | 0.79 | 0.01 | 1.6 |
| PKR | | 3 | 0.18 | 4 |

This is a 32 years old, 53kg female. She was admitted to ED as "sudden collapse at home after feeling unwell for about 12 hours with a 'flu-like illness". Her BP is 56/31 (MAP-39mmHg). Her GCS is 8. She was previously well and takes no medication apart from the oral contraceptive pill. Her haemoglobin was 134g/litre and her $SpO_2$ was 94%. Acute pulmonary embolus was being considered. Do you agree with the provisional diagnosis?

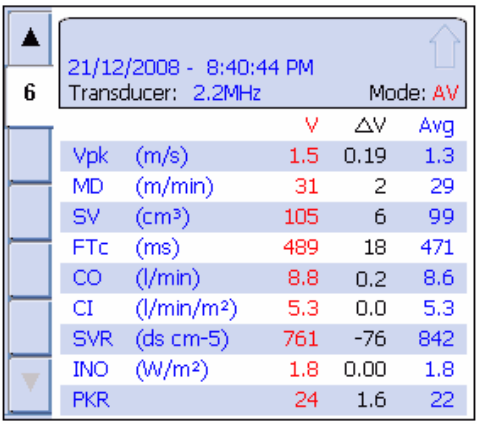
A bit more data might help, so can we calculate it from the data we have?

From CO/CI we can work out her BSA must be 1.64$m^2$. Her Stroke Volume Index (SVI) must be 95/1.64 = 58ml/$m^2$, or 1.8ml/kg – very high. We can work out her $DO_2$ as 1.34 x 134 x 10 x 94/100 = 1688 ml/min. From this and her BSA we know her $DO_2I$ = 1688/1.64 = 1029 ml/$m^2$/min which is well above normal. You might already have worked out that her heart rate is 105.

So what does all this mean? She is clearly hyperdynamic. It is not due to anaemia. Her $DO_2$ is very high, her SVR is very low and her BP is very low. According to the algorithm, this puts us fairly and squarely in the category of decompensated vascular collapse. But a PKR of just 3 told us this straight off. Something is clearly depressing her inotropy, to the extent of clinical left ventricular failure (see booklet 3, "The USCOM and Inotropy"). This isn't pulmonary embolus; this is full-blown septic shock!

How will you treat her? Does the FTc or SV/SVI indicate that she needs fluid? If her Smith-Madigan Inotropy Index ("INO") is just 0.79 will she respond to fluid? Would extra oxygen help? What would happen if we treated her with positive pressure ventilation? If you have come this far with the four USCOM booklets then you already know the answers to these questions. Congratulations, you're now ready to fly solo!

On a cheerful note, here's a set of USCOM data from a 23 year old 78Kg female with a blood pressure of 100/70 (MAP-83mmHg). She's fully conscious, apyrexial and quite happy to be in hospital. What is your diagnosis?



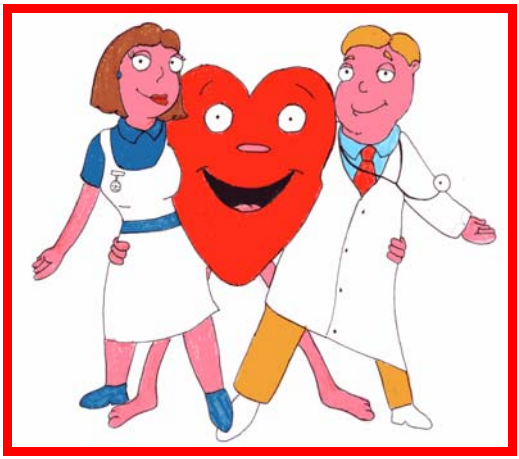

| | | V | ΔV | Avg |
|---|---|---|---|---|
| Vpk | (m/s) | 1.5 | 0.19 | 1.3 |
| MD | (m/min) | 31 | 2 | 29 |
| SV | (cm³) | 105 | 6 | 99 |
| FTc | (ms) | 489 | 18 | 471 |
| CO | (l/min) | 8.8 | 0.2 | 8.6 |
| CI | (l/min/m²) | 5.3 | 0.0 | 5.3 |
| SVR | (ds cm-5) | 761 | -76 | 842 |
| INO | (W/m²) | 1.8 | 0.00 | 1.8 |
| PKR | | 24 | 1.6 | 22 |

You might be interested to know that just an hour or so after this reading was taken she became a mother! Not all hyperdynamic states are pathological, unless of course you consider children to be little pathogens! Let's not go there...

## Conclusion.

With the USCOM we can measure the various components of the circulation and make sense of the overall haemodynamic picture. No one piece of information can give us the complete answer to exactly what is going on in any given patient. We need to look at the complex interplay of CO, SVR, $DO_2$, BP and much more. "Is $DO_2$ normal or abnormal?" is a question central to understanding haemodynamics. A normal $DO_2$ keeps us alive; an abnormal $DO_2$ is a very real threat to life, be it high or low!

However the fundamental question we must ask is "what are the tissues asking for and why?" Quantitative haemodynamics helps provide the answer which will then allow us to understand the underlying physiology or Pathophysiology. From this we can initiate rational and appropriate treatment and monitor the effects that treatment produces. Once we have achieved a normodynamic state then we are probably well on the way to ensuring patient recovery!



# Appendix 1 - Normal USCOM Values - Adult Aortic

| Age | Type | Vpk | Pmn | vti | MD | FT | FTc | SV | SVI | CO | Cl | MAP | SVR | SVRI | SVV | SW | CPO | SMII | PKR | D02 | D02I |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16 to 25 | **Mean** | **1.4** | **3.7** | **28** | **20** | **314** | **346** | **80** | **49** | **5.9** | **3.6** | **85** | **1221** | **2027** | **20** | **902** | **1.1** | **1.84** | **26** | **1121** | **681** |
| | Low | 1.2 | 2.5 | 23 | 16 | 286 | 314 | 64 | 40 | 4.6 | 2.8 | 74 | 942 | 1507 | 12 | 698 | 0.8 | 1.40 | 17 | 886 | 533 |
| | High | 1.7 | 4.9 | 33 | 25 | 343 | 378 | 96 | 58 | 7.1 | 4.3 | 96 | 1501 | 2546 | 27 | 1106 | 1.4 | 2.30 | 36 | 1356 | 829 |
| 26 to 35 | **Mean** | **1.2** | **2.7** | **26** | **18** | **343** | **365** | **76** | **43** | **5.8** | **3.5** | **94** | **1216** | **2110** | **21** | **924** | **1.1** | **1.62** | **31** | **1105** | **665** |
| | Low | 1.0 | 1.7 | 22 | 15 | 304 | 320 | 63 | 35 | 4.8 | 2.9 | 89 | 848 | 1454 | 12 | 779 | 0.8 | 1.30 | 16 | 911 | 546 |
| | High | 1.4 | 3.7 | 30 | 21 | 383 | 410 | 89 | 50 | 6.8 | 4.2 | 99 | 1583 | 2767 | 30 | 1069 | 1.3 | 2.00 | 46 | 1299 | 783 |
| 36 to 45 | **Mean** | **1.2** | **2.8** | **27** | **20** | **347** | **385** | **78** | **45** | **5.7** | **3.3** | **89** | **1291** | **2247** | **20** | **911** | **1.1** | **1.59** | **35** | **1087** | **624** |
| | Low | 1.1 | 2.0 | 23 | 16 | 311 | 345 | 65 | 38 | 4.7 | 2.7 | 84 | 1060 | 1842 | 11 | 771 | 0.9 | 1.30 | 24 | 891 | 518 |
| | High | 1.4 | 3.6 | 31 | 23 | 383 | 425 | 91 | 51 | 6.7 | 3.8 | 94 | 1523 | 2651 | 30 | 1051 | 1.3 | 1.80 | 45 | 1283 | 730 |
| 46 to 55 | **Mean** | **1.2** | **2.8** | **26** | **18** | **336** | **383** | **72** | **44** | **5.1** | **3.1** | **82** | **1336** | **2239** | **19** | **772** | **0.9** | **1.48** | **36** | **972** | **591** |
| | Low | 1.0 | 2.0 | 23 | 15 | 302 | 346 | 63 | 36 | 4.2 | 2.4 | 77 | 1084 | 1712 | 11 | 680 | 0.8 | 1.20 | 25 | 811 | 466 |
| | High | 1.4 | 3.7 | 30 | 22 | 370 | 420 | 81 | 51 | 5.9 | 3.7 | 87 | 1587 | 2766 | 26 | 865 | 1.1 | 1.80 | 47 | 1134 | 717 |
| > 55 | **Mean** | **1.0** | **2.1** | **24** | **16** | **354** | **370** | **63** | **40** | **4.2** | **2.7** | **82** | **1425** | **2221** | **21** | **604** | **0.7** | **1.13** | **37** | **795** | **509** |
| | Low | 0.9 | 1.6 | 21 | 13 | 325 | 347 | 55 | 35 | 3.5 | 2.2 | 78 | 1205 | 1876 | 12 | 509 | 0.5 | 1.00 | 28 | 667 | 430 |
| | High | 1.2 | 2.5 | 27 | 18 | 384 | 393 | 71 | 46 | 4.8 | 3.1 | 86 | 1646 | 2565 | 30 | 700 | 0.8 | 1.30 | 46 | 923 | 589 |
| | | m/s | mmHg | cm | m/min | ms | ms | ml | $ml/m^2$ | l/min | $l/min/m^2$ | mmHg | $d.s.cm^{-5}$ | $d.s.cm^{-5}m^2$ | % | mJ | W | $W/m^2$ | | ml/min | $ml/min/m^2$ |

These values are supplied as a guide only. The generalisability of these values to all subjects has not been confirmed. The author recommends that the normal values and ranges for any particular demographic group should be established locally.

# Appendix 2 - Normal USCOM Values - Adult Pulmonary

| Age | Type | Vpk | Pmn | vti | MD | FT | FTc | SV | SVI | CO | CI | MAP | SVR | SVRI | SVV | SW | CPO | SMII | PKR | D02 | D02I |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16 to 25 | **Mean** | **1.1** | **2.1** | **23** | **17** | **340** | **374** | **80** | **49** | **5.9** | **3.6** | **85** | **1221** | **2027** | **20** | **902** | **1.1** | **1.84** | **26** | **1121** | **681** |
| | Low | 0.9 | 1.4 | 19 | 14 | 309 | 339 | 64 | 40 | 4.6 | 2.8 | 74 | 942 | 1507 | 12 | 698 | 0.8 | 1.40 | 17 | 886 | 533 |
| | High | 1.3 | 2.8 | 27 | 20 | 370 | 408 | 96 | 58 | 7.1 | 4.3 | 96 | 1501 | 2546 | 27 | 1106 | 1.4 | 2.30 | 36 | 1356 | 829 |
| 26 to 35 | **Mean** | **0.9** | **1.6** | **21** | **15** | **371** | **394** | **76** | **43** | **5.8** | **3.5** | **94** | **1216** | **2110** | **21** | **924** | **1.1** | **1.62** | **31** | **1105** | **665** |
| | Low | 0.8 | 1.0 | 18 | 12 | 329 | 346 | 63 | 35 | 4.8 | 2.9 | 89 | 848 | 1454 | 12 | 779 | 0.8 | 1.30 | 16 | 911 | 546 |
| | High | 1.1 | 2.2 | 25 | 18 | 413 | 443 | 89 | 50 | 6.8 | 4.2 | 99 | 1583 | 2767 | 30 | 1069 | 1.3 | 2.00 | 46 | 1299 | 783 |
| 36 to 45 | **Mean** | **1.0** | **1.6** | **22** | **16** | **375** | **416** | **78** | **45** | **5.7** | **3.3** | **89** | **1291** | **2247** | **20** | **911** | **1.1** | **1.59** | **35** | **1087** | **624** |
| | Low | 0.8 | 1.2 | 19 | 13 | 336 | 373 | 65 | 38 | 4.7 | 2.7 | 84 | 1060 | 1842 | 11 | 771 | 0.9 | 1.30 | 24 | 891 | 518 |
| | High | 1.1 | 2.1 | 26 | 19 | 413 | 459 | 91 | 51 | 6.7 | 3.8 | 94 | 1523 | 2651 | 30 | 1051 | 1.3 | 1.80 | 45 | 1283 | 730 |
| 46 to 55 | **Mean** | **1.0** | **1.7** | **22** | **15** | **363** | **414** | **72** | **44** | **5.1** | **3.1** | **82** | **1336** | **2239** | **19** | **772** | **0.9** | **1.48** | **36** | **972** | **591** |
| | Low | 0.8 | 1.2 | 19 | 12 | 326 | 374 | 63 | 36 | 4.2 | 2.4 | 77 | 1084 | 1712 | 11 | 680 | 0.8 | 1.20 | 25 | 811 | 466 |
| | High | 1.1 | 2.1 | 25 | 18 | 400 | 454 | 81 | 51 | 5.9 | 3.7 | 87 | 1587 | 2766 | 26 | 865 | 1.1 | 1.80 | 47 | 1134 | 717 |
| > 55 | **Mean** | **0.8** | **1.2** | **20** | **13** | **382** | **400** | **63** | **40** | **4.2** | **2.7** | **82** | **1425** | **2221** | **21** | **604** | **0.7** | **1.13** | **37** | **795** | **509** |
| | Low | 0.7 | 0.9 | 17 | 11 | 350 | 375 | 55 | 35 | 3.5 | 2.2 | 78 | 1205 | 1876 | 12 | 509 | 0.5 | 1.00 | 28 | 667 | 430 |
| | High | 0.9 | 1.5 | 22 | 15 | 414 | 424 | 71 | 46 | 4.8 | 3.1 | 86 | 1646 | 2565 | 30 | 700 | 0.8 | 1.30 | 46 | 923 | 589 |
| | | m/s | mmHg | cm | m/min | ms | ms | ml | $ml/m^2$ | l/min | $l/min/m^2$ | mmHg | $d.s.cm^{-5}$ | $d.s.cm^{-5}m^2$ | % | mJ | W | $W/m^2$ | | ml/min | $ml/min/m^2$ |

These values are supplied as a guide only. The generalisability of these values to all subjects has not been confirmed. The author recommends that the normal values and ranges for any particular demographic group should be established locally.

# Appendix 3 - Normal USCOM Values - Paediatric Aortic – Neonate to 6 years

| Age | Type | BSA | Vpk | vti | HR | MD | FT | FTc | SV | SVI | CO | CI | Hb | D02 | D02I | SBP | DBP | MAP | SVR | SVRI | SMII | PKR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 to | **Mean** | **0.22** | **1.13** | **16.4** | **125** | **17.9** | **239** | **355** | **5.5** | **25** | **0.78** | **3.5** | **155** | **162** | **736** | **73** | **39** | **50** | **5068** | **1405** | **0.71** | **33** |
| 30 | Low | 0.18 | 0.96 | 14.2 | 115 | 16.0 | 214 | 326 | 4.2 | 20 | 0.62 | 3.1 | 142 | 129 | 637 | 64 | 29 | 41 | 3679 | 1204 | 0.60 | 27 |
| days | High | 0.26 | 1.30 | 18.6 | 135 | 19.8 | 264 | 384 | 6.8 | 30 | 0.94 | 4.0 | 168 | 195 | 836 | 83 | 50 | 59 | 6457 | 1606 | 0.82 | 38 |
| 1 to | **Mean** | **0.41** | **1.31** | **20.5** | **124** | **25.4** | **255** | **363** | **14.8** | **36** | **1.83** | **4.4** | **125** | **306** | **740** | **85** | **52** | **63** | **2889** | **1191** | **1.24** | **23** |
| 12 | Low | 0.35 | 1.12 | 18.4 | 103 | 20.9 | 224 | 339 | 12.9 | 31 | 1.49 | 3.7 | 103 | 250 | 623 | 68 | 37 | 50 | 2111 | 919 | 1.08 | 15 |
| mths | High | 0.48 | 1.50 | 22.6 | 145 | 29.9 | 285 | 386 | 16.6 | 40 | 2.16 | 5.1 | 147 | 362 | 858 | 102 | 68 | 76 | 3666 | 1464 | 1.40 | 32 |
| | **Mean** | **0.50** | **1.39** | **21.8** | **119** | **25.6** | **259** | **362** | **19.8** | **39** | **2.32** | **4.6** | **118** | **365** | **732** | **90** | **50** | **64** | **2256** | **1125** | **1.45** | **21** |
| 1 | Low | 0.42 | 1.16 | 19.2 | 110 | 22.6 | 232 | 326 | 16.5 | 34 | 1.99 | 4.1 | 96 | 314 | 646 | 73 | 34 | 49 | 1790 | 904 | 1.03 | 14 |
| | High | 0.58 | 1.62 | 24.3 | 128 | 28.7 | 285 | 398 | 23.1 | 44 | 2.65 | 5.2 | 139 | 417 | 818 | 107 | 67 | 78 | 2722 | 1345 | 1.88 | 28 |
| | **Mean** | **0.60** | **1.38** | **26.2** | **104** | **26.8** | **305** | **398** | **29.1** | **49** | **2.96** | **5.0** | **117** | **464** | **777** | **96** | **53** | **67** | **1879** | **1120** | **1.50** | **22** |
| 2 | Low | 0.49 | 1.18 | 21.8 | 90 | 22.3 | 277 | 371 | 23.0 | 40 | 2.46 | 4.1 | 94 | 386 | 647 | 76 | 35 | 50 | 1486 | 884 | 1.23 | 15 |
| | High | 0.70 | 1.59 | 30.6 | 118 | 31.3 | 333 | 425 | 35.2 | 57 | 3.46 | 5.8 | 140 | 543 | 907 | 116 | 72 | 85 | 2273 | 1356 | 1.78 | 30 |
| | **Mean** | **0.68** | **1.49** | **27.9** | **99** | **27.4** | **303** | **387** | **35.3** | **52** | **3.45** | **5.1** | **114** | **528** | **774** | **102** | **55** | **71** | **1713** | **1166** | **1.70** | **20** |
| 3 | Low | 0.54 | 1.27 | 23.6 | 86 | 22.6 | 270 | 345 | 28.4 | 43 | 2.78 | 4.1 | 93 | 425 | 622 | 80 | 37 | 54 | 1290 | 876 | 1.37 | 13 |
| | High | 0.82 | 1.71 | 32.2 | 112 | 32.2 | 336 | 429 | 42.2 | 61 | 4.13 | 6.1 | 135 | 631 | 926 | 124 | 73 | 87 | 2136 | 1457 | 2.03 | 27 |
| | **Mean** | **0.74** | **1.54** | **29.1** | **95** | **27.6** | **312** | **390** | **40.4** | **55** | **3.82** | **5.2** | **115** | **589** | **794** | **102** | **53** | **69** | **1504** | **1107** | **1.72** | **18** |
| 4 | Low | 0.57 | 1.33 | 25.4 | 81 | 22.4 | 281 | 350 | 33.5 | 47 | 3.02 | 4.1 | 94 | 465 | 631 | 81 | 33 | 52 | 1204 | 890 | 1.37 | 13 |
| | High | 0.91 | 1.74 | 32.9 | 109 | 32.8 | 342 | 430 | 47.3 | 63 | 4.62 | 6.2 | 136 | 712 | 956 | 122 | 72 | 85 | 1805 | 1323 | 2.07 | 24 |
| | **Mean** | **0.80** | **1.47** | **29.1** | **89** | **25.6** | **322** | **390** | **44.7** | **56** | **3.93** | **4.9** | **117** | **616** | **768** | **103** | **54** | **70** | **1477** | **1176** | **1.71** | **20** |
| 5 | Low | 0.64 | 1.27 | 25.3 | 78 | 21.4 | 298 | 356 | 37.4 | 48 | 3.18 | 4.1 | 98 | 499 | 641 | 79 | 35 | 52 | 1166 | 947 | 1.41 | 15 |
| | High | 0.97 | 1.68 | 33.0 | 100 | 29.9 | 347 | 423 | 52.0 | 64 | 4.67 | 5.7 | 136 | 733 | 895 | 126 | 73 | 88 | 1787 | 1405 | 2.01 | 26 |
| | **Mean** | **0.88** | **1.48** | **29.6** | **85** | **25.1** | **323** | **383** | **49.3** | **56** | **4.16** | **4.8** | **116** | **647** | **739** | **107** | **56** | **73** | **1459** | **1269** | **1.80** | **21** |
| 6 | Low | 0.67 | 1.27 | 25.6 | 73 | 20.7 | 301 | 353 | 40.6 | 49 | 3.35 | 3.9 | 95 | 520 | 605 | 82 | 35 | 54 | 1148 | 1014 | 1.44 | 12 |
| | High | 1.08 | 1.69 | 33.7 | 97 | 29.4 | 346 | 413 | 58.0 | 64 | 4.98 | 5.6 | 137 | 774 | 874 | 132 | 77 | 93 | 1771 | 1525 | 2.17 | 30 |
| | | $m^2$ | m/s | cm | bpm | m/min | ms | ms | ml | $ml/m^2$ | l/min | $l/min/m^2$ | g/l | ml/min | $ml/min/m^2$ | mmHg | mmHg | mmHg | $d.s.cm^{-5}$ | $d.s.cm^{-5}m^2$ | $W/m^2$ | |

These values are supplied as a guide only. The generalisability of these values to all subjects has not been confirmed. The author recommends that the normal values and ranges for any particular demographic group should be established locally.

# Appendix 4 - Normal USCOM Values - Paediatric Aortic – 7 to 16 years

| Age | Type | BSA | Vpk | vti | HR | MD | FT | FTc | SV | SVI | CO | CI | Hb | D02 | D02I | SBP | DBP | MAP | SVR | SVRI | SMII | PKR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Mean** | **0.94** | **1.52** | **30.2** | **84** | **25.3** | **322** | **379** | **53.8** | **58** | **4.48** | **4.8** | **115** | **691** | **736** | **111** | **58** | **76** | **1393** | **1290** | **1.91** | **20** |
| 7 | Low | 0.71 | 1.32 | 26.3 | 71 | 21.1 | 298 | 349 | 43.6 | 49 | 3.60 | 4.0 | 93 | 555 | 606 | 87 | 42 | 59 | 1141 | 1073 | 1.56 | 15 |
| | High | 1.17 | 1.72 | 34.1 | 97 | 29.5 | 346 | 409 | 63.9 | 66 | 5.36 | 5.7 | 137 | 826 | 867 | 135 | 74 | 93 | 1645 | 1507 | 2.26 | 26 |
| | **Mean** | **1.03** | **1.50** | **30.4** | **84** | **25.2** | **328** | **384** | **59.1** | **58** | **4.90** | **4.8** | **116** | **761** | **741** | **114** | **60** | **78** | **1323** | **1343** | **1.94** | **22** |
| 8 | Low | 0.74 | 1.25 | 25.7 | 71 | 20.4 | 302 | 353 | 48.0 | 49 | 3.86 | 3.9 | 91 | 600 | 592 | 90 | 44 | 61 | 1058 | 1078 | 1.56 | 15 |
| | High | 1.31 | 1.74 | 35.1 | 96 | 30.1 | 353 | 415 | 70.2 | 67 | 5.94 | 5.8 | 141 | 923 | 889 | 137 | 76 | 95 | 1589 | 1607 | 2.32 | 28 |
| | **Mean** | **1.12** | **1.45** | **30.0** | **83** | **24.8** | **332** | **387** | **62.3** | **57** | **5.17** | **4.7** | **118** | **817** | **731** | **113** | **60** | **78** | **1268** | **1373** | **1.88** | **23** |
| 9 | Low | 0.80 | 1.21 | 25.7 | 70 | 19.4 | 305 | 356 | 51.2 | 49 | 3.86 | 3.8 | 96 | 610 | 587 | 90 | 44 | 61 | 1004 | 1121 | 1.48 | 16 |
| | High | 1.43 | 1.69 | 34.4 | 96 | 30.3 | 358 | 418 | 73.5 | 65 | 6.47 | 5.6 | 140 | 1023 | 875 | 136 | 76 | 95 | 1531 | 1625 | 2.29 | 29 |
| | **Mean** | **1.22** | **1.53** | **31.4** | **77** | **24.0** | **331** | **372** | **70.0** | **58** | **5.36** | **4.5** | **120** | **861** | **706** | **115** | **61** | **79** | **1245** | **1491** | **1.96** | **21** |
| 10 | Low | 0.86 | 1.29 | 26.7 | 65 | 19.2 | 306 | 344 | 56.2 | 48 | 4.07 | 3.5 | 97 | 654 | 553 | 92 | 47 | 63 | 949 | 1116 | 1.56 | 15 |
| | High | 1.58 | 1.76 | 36.1 | 89 | 28.8 | 357 | 401 | 83.9 | 68 | 6.64 | 5.4 | 143 | 1068 | 859 | 139 | 76 | 95 | 1541 | 1867 | 2.37 | 27 |
| | **Mean** | **1.29** | **1.51** | **31.1** | **78** | **24.0** | **330** | **374** | **73.8** | **57** | **5.71** | **4.5** | **120** | **918** | **709** | **117** | **62** | **80** | **1174** | **1498** | **1.97** | **21** |
| 11 | Low | 0.96 | 1.32 | 26.8 | 66 | 19.8 | 305 | 340 | 60.6 | 49 | 4.49 | 3.6 | 99 | 723 | 572 | 94 | 46 | 64 | 917 | 1181 | 1.60 | 16 |
| | High | 1.63 | 1.71 | 35.3 | 90 | 28.3 | 355 | 408 | 87.1 | 65 | 6.93 | 5.3 | 141 | 1114 | 846 | 140 | 79 | 97 | 1430 | 1815 | 2.33 | 27 |
| | **Mean** | **1.35** | **1.74** | **34.9** | **81** | **28.2** | **331** | **382** | **86.0** | **64** | **6.92** | **5.1** | **120** | **1113** | **823** | **122** | **63** | **83** | **988** | **1323** | **2.29** | **17** |
| 12 | Low | 0.99 | 1.45 | 30.6 | 68 | 23.0 | 308 | 355 | 71.3 | 57 | 5.55 | 4.3 | 98 | 892 | 687 | 106 | 42 | 65 | 805 | 1090 | 1.84 | 12 |
| | High | 1.72 | 2.04 | 39.3 | 94 | 33.4 | 353 | 409 | 100.6 | 70 | 8.29 | 6.0 | 142 | 1333 | 959 | 139 | 84 | 101 | 1171 | 1556 | 2.73 | 22 |
| 13 | **Mean** | **1.49** | **1.78** | **35.8** | **79** | **25.2** | **333** | **376** | **92.3** | **62** | **6.88** | **4.6** | **124** | **1143** | **767** | **124** | **65** | **85** | **991** | **1476** | **2.17** | **22** |
| to | Low | 1.17 | 1.57 | 31.5 | 67 | 20.5 | 310 | 344 | 79.4 | 53 | 5.61 | 3.7 | 99 | 939 | 622 | 103 | 47 | 67 | 740 | 1102 | 1.74 | 17 |
| 16 | High | 1.81 | 1.99 | 40.1 | 92 | 29.9 | 356 | 408 | 105.2 | 71 | 8.15 | 5.6 | 149 | 1347 | 912 | 145 | 83 | 103 | 1242 | 1850 | 2.60 | 28 |
| | | $m^2$ | m/s | cm | bpm | m/min | ms | ms | ml | $ml/m^2$ | l/min | $l/min/m^2$ | g/l | ml/min | $ml/min/m^2$ | mmHg | mmHg | mmHg | $d.s.cm^{-5}$ | $d.s.cm^{-5}m^2$ | $W/m^2$ | |

These values are supplied as a guide only. The generalisability of these values to all subjects has not been confirmed. The author recommends that the normal values and ranges for any particular demographic group should be established locally.

# Appendix 5 - Normal USCOM Values - Paediatric Pulmonary – Neonate to 6 years

| Age | Type | BSA | Vpk | vti | HR | MD | FT | FTc | SV | SVI | CO | CI | Hb | D02 | D02I | SBP | DBP | MAP | SVR | SVRI | SMII | PKR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 to | **Mean** | **0.22** | **0.86** | **13.5** | **125** | **14.8** | **258** | **383** | **5.50** | **25** | **0.78** | **3.5** | **155** | **162** | **736** | **73** | **39** | **50** | **5068** | **1405** | **0.71** | **33** |
| 30 | Low | 0.18 | 0.73 | 11.8 | 115 | 13.2 | 231 | 352 | 4.20 | 20 | 0.62 | 3.1 | 142 | 129 | 637 | 64 | 29 | 41 | 3679 | 1204 | 0.60 | 27 |
| days | High | 0.26 | 0.99 | 15.3 | 135 | 16.4 | 285 | 414 | 6.80 | 30 | 0.94 | 4.0 | 168 | 195 | 836 | 83 | 50 | 59 | 6457 | 1606 | 0.82 | 38 |
| 1 to | **Mean** | **0.41** | **0.99** | **16.9** | **124** | **21.0** | **275** | **392** | **14.8** | **36** | **1.83** | **4.4** | **125** | **306** | **740** | **85** | **52** | **63** | **2889** | **1191** | **1.24** | **23** |
| 12 | Low | 0.35 | 0.85 | 15.2 | 103 | 17.2 | 242 | 366 | 12.9 | 31 | 1.49 | 3.7 | 103 | 250 | 623 | 68 | 37 | 50 | 2111 | 919 | 1.08 | 15 |
| mths | High | 0.48 | 1.14 | 18.6 | 145 | 24.7 | 308 | 417 | 16.6 | 40 | 2.16 | 5.1 | 147 | 362 | 858 | 102 | 68 | 76 | 3666 | 1464 | 1.40 | 32 |
| | **Mean** | **0.50** | **1.06** | **18.0** | **119** | **21.2** | **279** | **391** | **19.8** | **39** | **2.32** | **4.6** | **118** | **365** | **732** | **90** | **50** | **64** | **2256** | **1125** | **1.45** | **21** |
| 1 | Low | 0.42 | 0.88 | 15.8 | 110 | 18.7 | 251 | 352 | 16.5 | 34 | 1.99 | 4.1 | 96 | 314 | 646 | 73 | 34 | 49 | 1790 | 904 | 1.03 | 14 |
| | High | 0.58 | 1.23 | 20.1 | 128 | 23.7 | 308 | 429 | 23.1 | 44 | 2.65 | 5.2 | 139 | 417 | 818 | 107 | 67 | 78 | 2722 | 1345 | 1.88 | 28 |
| | **Mean** | **0.60** | **1.05** | **21.6** | **104** | **22.1** | **330** | **430** | **29.1** | **49** | **2.96** | **5.0** | **117** | **464** | **777** | **96** | **53** | **67** | **1879** | **1120** | **1.50** | **22** |
| 2 | Low | 0.49 | 0.90 | 18.0 | 90 | 18.4 | 300 | 401 | 23.0 | 40 | 2.46 | 4.1 | 94 | 386 | 647 | 76 | 35 | 50 | 1486 | 884 | 1.23 | 15 |
| | High | 0.70 | 1.21 | 25.3 | 118 | 25.9 | 360 | 459 | 35.2 | 57 | 3.46 | 5.8 | 140 | 543 | 907 | 116 | 72 | 85 | 2273 | 1356 | 1.78 | 30 |
| | **Mean** | **0.68** | **1.13** | **23.0** | **99** | **22.7** | **327** | **418** | **35.3** | **52** | **3.45** | **5.1** | **114** | **528** | **774** | **102** | **55** | **71** | **1713** | **1166** | **1.70** | **20** |
| 3 | Low | 0.54 | 0.97 | 19.5 | 86 | 18.7 | 292 | 373 | 28.4 | 43 | 2.78 | 4.1 | 93 | 425 | 622 | 80 | 37 | 54 | 1290 | 876 | 1.37 | 13 |
| | High | 0.82 | 1.30 | 26.6 | 112 | 26.6 | 363 | 464 | 42.2 | 61 | 4.13 | 6.1 | 135 | 631 | 926 | 124 | 73 | 87 | 2136 | 1457 | 2.03 | 27 |
| | **Mean** | **0.74** | **1.17** | **24.1** | **95** | **22.8** | **337** | **421** | **40.4** | **55** | **3.82** | **5.2** | **115** | **589** | **794** | **102** | **53** | **69** | **1504** | **1107** | **1.72** | **18** |
| 4 | Low | 0.57 | 1.01 | 20.9 | 81 | 18.5 | 303 | 378 | 33.5 | 47 | 3.02 | 4.1 | 94 | 465 | 631 | 81 | 33 | 52 | 1204 | 890 | 1.37 | 13 |
| | High | 0.91 | 1.33 | 27.2 | 109 | 27.1 | 370 | 464 | 47.3 | 63 | 4.62 | 6.2 | 136 | 712 | 956 | 122 | 72 | 85 | 1805 | 1323 | 2.07 | 24 |
| | **Mean** | **0.80** | **1.12** | **24.1** | **89** | **21.2** | **348** | **421** | **44.7** | **56** | **3.93** | **4.9** | **117** | **616** | **768** | **103** | **54** | **70** | **1477** | **1176** | **1.71** | **20** |
| 5 | Low | 0.64 | 0.96 | 20.9 | 78 | 17.7 | 322 | 385 | 37.4 | 48 | 3.18 | 4.1 | 98 | 499 | 641 | 79 | 35 | 52 | 1166 | 947 | 1.41 | 15 |
| | High | 0.97 | 1.27 | 27.3 | 100 | 24.7 | 374 | 457 | 52.0 | 64 | 4.67 | 5.7 | 136 | 733 | 895 | 126 | 73 | 88 | 1787 | 1405 | 2.01 | 26 |
| | **Mean** | **0.88** | **1.13** | **24.5** | **85** | **20.7** | **349** | **414** | **49.3** | **56** | **4.16** | **4.8** | **116** | **647** | **739** | **107** | **56** | **73** | **1459** | **1269** | **1.80** | **21** |
| 6 | Low | 0.67 | 0.97 | 21.2 | 73 | 17.1 | 325 | 382 | 40.6 | 49 | 3.35 | 3.9 | 95 | 520 | 605 | 82 | 35 | 54 | 1148 | 1014 | 1.44 | 12 |
| | High | 1.08 | 1.29 | 27.8 | 97 | 24.3 | 373 | 446 | 58.0 | 64 | 4.98 | 5.6 | 137 | 774 | 874 | 132 | 77 | 93 | 1771 | 1525 | 2.17 | 30 |
| | | $m^2$ | m/s | cm | bpm | m/min | ms | ms | ml | $ml/m^2$ | l/min | $l/min/m^2$ | g/l | ml/min | $ml/min/m^2$ | mmHg | mmHg | mmHg | $d.s.cm^{-5}$ | $d.s.cm^{-5}m^2$ | $W/m^2$ | |

These values are supplied as a guide only. The generalisability of these values to all subjects has not been confirmed. The author recommends that the normal values and ranges for any particular demographic group should be established locally.

# Appendix 6 - Normal USCOM Values - Paediatric Pulmonary – 7 to 16 years

| Age | Type | BSA | Vpk | vti | HR | MD | FT | FTc | SV | SVI | CO | CI | Hb | D02 | D02I | SBP | DBP | MAP | SVR | SVRI | SMII | PKR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Mean** | **0.94** | **1.16** | **25.0** | **84** | **20.9** | **348** | **409** | **53.8** | **58** | **4.48** | **4.8** | **115** | **691** | **736** | **111** | **58** | **76** | **1393** | **1290** | **1.91** | **20** |
| 7 | Low | 0.71 | 1.00 | 21.7 | 71 | 17.4 | 322 | 377 | 43.6 | 49 | 3.60 | 4.0 | 93 | 555 | 606 | 87 | 42 | 59 | 1141 | 1073 | 1.56 | 15 |
| | High | 1.17 | 1.31 | 28.2 | 97 | 24.3 | 374 | 442 | 63.9 | 66 | 5.36 | 5.7 | 137 | 826 | 867 | 135 | 74 | 93 | 1645 | 1507 | 2.26 | 26 |
| | **Mean** | **1.03** | **1.14** | **25.1** | **84** | **20.8** | **354** | **415** | **59.1** | **58** | **4.90** | **4.8** | **116** | **761** | **741** | **114** | **60** | **78** | **1323** | **1343** | **1.94** | **22** |
| 8 | Low | 0.74 | 0.95 | 21.2 | 71 | 16.9 | 326 | 381 | 48.0 | 49 | 3.86 | 3.9 | 91 | 600 | 592 | 90 | 44 | 61 | 1058 | 1078 | 1.56 | 15 |
| | High | 1.31 | 1.33 | 29.0 | 96 | 24.8 | 381 | 449 | 70.2 | 67 | 5.94 | 5.8 | 141 | 923 | 889 | 137 | 76 | 95 | 1589 | 1607 | 2.32 | 28 |
| | **Mean** | **1.12** | **1.10** | **24.8** | **83** | **20.5** | **358** | **418** | **62.3** | **57** | **5.17** | **4.7** | **118** | **817** | **731** | **113** | **60** | **78** | **1268** | **1373** | **1.88** | **23** |
| 9 | Low | 0.80 | 0.92 | 21.2 | 70 | 16.0 | 329 | 385 | 51.2 | 49 | 3.86 | 3.8 | 96 | 610 | 587 | 90 | 44 | 61 | 1004 | 1121 | 1.48 | 16 |
| | High | 1.43 | 1.28 | 28.4 | 96 | 25.0 | 387 | 452 | 73.5 | 65 | 6.47 | 5.6 | 140 | 1023 | 875 | 136 | 76 | 95 | 1531 | 1625 | 2.29 | 29 |
| | **Mean** | **1.22** | **1.16** | **25.9** | **77** | **19.8** | **358** | **402** | **70.0** | **58** | **5.36** | **4.5** | **120** | **861** | **706** | **115** | **61** | **79** | **1245** | **1491** | **1.96** | **21** |
| 10 | Low | 0.86 | 0.98 | 22.0 | 65 | 15.8 | 331 | 371 | 56.2 | 48 | 4.07 | 3.5 | 97 | 654 | 553 | 92 | 47 | 63 | 949 | 1116 | 1.56 | 15 |
| | High | 1.58 | 1.34 | 29.8 | 89 | 23.8 | 385 | 433 | 83.9 | 68 | 6.64 | 5.4 | 143 | 1068 | 859 | 139 | 76 | 95 | 1541 | 1867 | 2.37 | 27 |
| | **Mean** | **1.29** | **1.15** | **25.7** | **78** | **19.9** | **356** | **404** | **73.8** | **57** | **5.71** | **4.5** | **120** | **918** | **709** | **117** | **62** | **80** | **1174** | **1498** | **1.97** | **21** |
| 11 | Low | 0.96 | 1.00 | 22.2 | 66 | 16.3 | 329 | 367 | 60.6 | 49 | 4.49 | 3.6 | 99 | 723 | 572 | 94 | 46 | 64 | 917 | 1181 | 1.60 | 16 |
| | High | 1.63 | 1.30 | 29.2 | 90 | 23.4 | 384 | 441 | 87.1 | 65 | 6.93 | 5.3 | 141 | 1114 | 846 | 140 | 79 | 97 | 1430 | 1815 | 2.33 | 27 |
| | **Mean** | **1.35** | **1.32** | **28.9** | **81** | **23.3** | **357** | **413** | **86.0** | **64** | **6.92** | **5.1** | **120** | **1113** | **823** | **122** | **63** | **83** | **988** | **1323** | **2.29** | **17** |
| 12 | Low | 0.99 | 1.10 | 25.3 | 68 | 19.0 | 333 | 384 | 71.3 | 57 | 5.55 | 4.3 | 98 | 892 | 687 | 106 | 42 | 65 | 805 | 1090 | 1.84 | 12 |
| | High | 1.72 | 1.55 | 32.5 | 94 | 27.6 | 381 | 441 | 100.6 | 70 | 8.29 | 6.0 | 142 | 1333 | 959 | 139 | 84 | 101 | 1171 | 1556 | 2.73 | 22 |
| 13 | **Mean** | **1.49** | **1.35** | **29.6** | **79** | **20.8** | **360** | **406** | **92.3** | **62** | **6.88** | **4.6** | **124** | **1143** | **767** | **124** | **65** | **85** | **991** | **1476** | **2.17** | **22** |
| to | Low | 1.17 | 1.19 | 26.0 | 67 | 16.9 | 335 | 372 | 79.4 | 53 | 5.61 | 3.7 | 99 | 939 | 622 | 103 | 47 | 67 | 740 | 1102 | 1.74 | 17 |
| 16 | High | 1.81 | 1.51 | 33.1 | 92 | 24.7 | 384 | 441 | 105.2 | 71 | 8.15 | 5.6 | 149 | 1347 | 912 | 145 | 83 | 103 | 1242 | 1850 | 2.60 | 28 |
| | | $m^2$ | m/s | cm | bpm | m/min | ms | ms | ml | $ml/m^2$ | l/min | $l/min/m^2$ | g/l | ml/min | $ml/min/m^2$ | mmHg | mmHg | mmHg | $d.s.cm^{-5}$ | $d.s.cm^{-5}m^2$ | $W/m^2$ | |

These values are supplied as a guide only. The generalisability of these values to all subjects has not been confirmed. The author recommends that the normal values and ranges for any particular demographic group should be established locally.