THE APPLICATION OF BASIC SCIENCE TO PRACTICAL PAEDIATRIC ANAESTHESIA

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This paper will attempt to show how a sound knowledge of anatomy, physiology, pharmacology and psychology of infants and children and how they differ from adults helps to improve their care during anaesthesia and the perioperative period.

A baby can be taken from the parent without undue distress up to 6 to 7 months of age while an older infant or young child will become very distressed and hence they should be accompanied by a parent to induction of anaesthesia provided the parent doesn't exhibit undue anxiety. In such cases it may be better to give the child some premedication. Older children can cope but many like to be accompanied by a parent. Sometimes children, particularly boys of 8 to10 years old, appear well adjusted when seen beforehand but show signs of extreme apprehension when they reach the induction room - this presents as almost invisible veins so that venepuncture is difficult. Again, premedication should be considered. Midazolam 0.2-0.3 mg/kg given orally 30 to 45 minutes before anaesthesia usually has a tranquilising effect. If a child is very distressed on arrival at the operating theatre 0.2mg/kg can be squirted into the nose. It may sting but it usually has an effect within about 10 minutes. In older children diazepam (0.3 mg/kg) or temazepam can be given an hour before induction. This may be accompanied by an analgesic such as paracetamol (30mg/kg orally). An apprehensive patient has an increased cardiac output, which is largely redistributed to muscle so that the injected or inhaled induction agent does not reach the target organ - the brain - unless substantially increased doses are given. The increased ventilation through crying does not necessarily speed induction - the increased uptake merely compensates for the drug which has been redistributed to muscle.

It is often said that children are like small adults. This is not so - for a start their proportions differ. Infants have a relatively large head and therefore brain. It must receive a greater proportion of cardiac output as a consequence. The surface area is larger and thus heat loss is increased when it is exposed, especially in neurosurgery.

The **surface area: body weight ratio is double** in infants compared to adults resulting in greater heat loss. **Oxygen consumption relative to body weight is also double** (6-7 mls/kg/min). This is another key to working out important differences because if they need double the volume of oxygen then they have to double the amount taken in and transported. This means the alveolar ventilation must be increased which is largely achieved by increasing respiratory rate. Cardiac output must also be doubled to carry the oxygen around the body - this is achieved by increasing heart rate as babies have a very limited ability to increase stroke volume. Thus heart rates of 120 - 160 are common. The increased work of doing this is minimized by having a lower vascular resistance so that babies systolic blood pressures are lower (70 - 80 mmHg).

The fixed stroke volume in infants is also important because anything that causes bradycardia such as hypoxia, deep halothane anaesthesia, or reflex bradycardia due to vagal stimulation, such as occurs during laryngoscopy, will result in a decrease in cardiac output. When combinations of these occur serious decreases in output can result.

Cardiac output can be assessed clinically with a stethoscope because heart sounds become softer as the output decreases. Normally blood flow into the ventricles or into the aorta and pulmonary artery causes expansion followed by an elastic recoil which slams the valves closed resulting in loud heart sounds. If the volume decreases the recoil is diminished and the resulting heart sounds become soft. When the cause is corrected, such as by giving blood or fluids in hypovolaemia, one can hear the sounds becoming louder. The stethoscope is thus a very useful and sensitive monitor with which it is also easy to differentiate between patient and equipment problems when a monitor such as an oximeter gives abnormal readings.

Ventilation is greatly influenced by the anatomical differences, especially the structure of the chest wall. The ribs in neonates are more horizontal limiting antero-posterior expansion of the chest and they lack the bucket handle movement of the middle ribs that allows lateral expansion of the thoracic cage in older patients. The consequence is that ventilation is much more dependent on diaphragmatic movement and hence anything that restricts it (abdominal distention or compression) will cause respiratory difficulties. This includes inflation of the stomach with gas which can occur during ventilation with a mask when too high a pressure is applied or the bag is squeezed too fast thereby forcing gas down the oesophagus as well as the trachea. In patients with oesophageal atresia stomach distention is more likely with positive pressure ventilation when there is a large fistula. This can been assessed beforehand with a lateral chest X ray which shows the air containing fistula. Beware if this is more than 2.5mm in diameter. Patients in the lithotomy position have their abdominal contents compressed forcing the diaphragm up and restricting ventilation.

Intubation technique is important because infants have a higher oxygen consumption (6-7ml/kg/minute compared to 3 in an adult). This results in there being a shorter time before hypoxia begins to develop when a paralysed baby is not being ventilated. There are anatomical differences in the airway which are relevant. The larynx is situated at a higher level relative to the vertebrae - C3 in the infant compared to C6 in the adult; the epiglottis is U shaped and relatively longer, the angle of the mandible is greater (120 degrees) and the trachea has an anterior inclination. In addition the relatively large head does not need to be on a pillow but needs to be stabilized. This can be done by slightly extending the neck, rolling the thenar eminence of the right hand on to the forehead to stabilize it, then opening the mouth with the index finger and inserting the laryngoscope with the left hand down the right hand side of the mouth so that the tongue is kept out of the way. If the laryngoscope is held between the thumb and index finger the little finger of the left hand can reach to press the larynx backwards thus bringing the larynx into view (figures 1 - 3). The tube can then be passed from the right corner of the mouth so that it does not obstruct the view of the larynx. The important anatomical points in relation to the tube are that the cricoid cartilage forms the narrowest part of the larnyx before puberty and because it is circular an uncuffed tube can be used until 10 -12 years of age. Another convenient point is that the nose accommodates the same size of tube as the larynx before puberty. Tracheal length is often quoted to be 4cms but Anneke Meursing showed that the mean length is 4.5cms in a 3 kg baby. The importance of tracheal length is to appreciate how far the tube can be passed without going into the bronchus. The problem is that there are occasional babies who have short tracheas. It is thus important always to check after intubation that both lungs are being ventilated.

Figure 1

Figure 2

Figure 3

Blood volume and haemoglobin are greater in newborns. The volume is about 80-85 ml.

Haemoglobin at full term is about 180-200gm/l decreasing to about 110gm/l at 3-6 months. This haemoglobin is predominantly fetal with alpha and gamma chains which enable it to take up oxygen at low tensions such as exist in the placenta but do not release it as readily to the tissues. Gradually it changes to adult haemoglobin (alpha and beta chains). As lowering $PaCO_2$ shifts the oxygen dissociation curve to the left, hyperventilation further reduces oxygen delivery to the tissues so that excessive hyperventilation should be avoided even by increasing dead space in the circuit - not shortening the endotracheal tube will help.

In neonates with a high haemoglobin, albumin rather than blood can be used for early transfusion, when needed. In premature infants haemoglobin tends to be low because most of the iron stores are laid down in the last three months of pregnancy.

Several factors should be considered in deciding that it is necessary to start a blood transfusion. The haemoglobin should be at a level above that which supplies minimal oxygen requirements for metabolism. In infants metabolic rate is higher, the haemoglobin level may be higher in full term babies but lower in prematures and between 3-6 months so that the tolerated blood loss will vary. A 20% loss is usually well tolerated provided fluids are given to maintain the circulating volume. At that point one might consider whether blood loss is likely to continue and, if haemoglobin was low to start with, then blood may be started. On the other hand, clinical signs such as a rising pulse, when apparently adequate fluids have been given or a bolus does not reduce the pulse in a patient who also looks pale, will usually suggest that it is time to start blood.

The total **body water** is about 80% of body weight at birth, gradually decreasing with age to 60-65 % in adults. Premature infants have relatively more, making fluid loss an even more critical problem to them. When neonates and infants become dehydrated they initially lose extracellular water. Because the extracellular space is relatively larger at this age (about 50% of body weight) the losses will be proportionately greater.The relatively smaller intracellular compartment then has less fluid to shift to the extracellular space when losses occur resulting in a much sicker infant than an adult might be in similar circumstances.

The other consequence of the relatively **large extracellular** space is that drugs predominantly distributed in the extracellular space will have to be given with a larger loading dose. Also, extracellular electrolytes such as chloride will have to be given in larger amounts to correct deficits which occur, for example in pyloric stenosis, because of the larger extracellular compartment.

Kidney function is immature at birth and although the various functions develop at different rates there is a rapid improvement in the first few weeks of life. The relevance is that fluids ,electrolytes and drugs excreted by the kidney are handled more slowly during the early days and weeks of life. Glomerular filtration is less, the cortical tubules which are important in sodium excretion are not fully developed, and the interstitial urea concentration in the loops of Henle is low (because the amino acids are being utilized to build cells) and hence water reabsorption is reduced.

The **brain** is immature. Centrally acting drugs such as morphine and barbiturates have a greater depressant effect and thus have to be used in reduced doses, if at all.

The **temperature** regulating centres are also immature so that body temperature control is less efficient. This problem is aggravated in neonates because they have a relatively large surface area (2-2.5 times relative to weight), thin skin and subcutaneous fat so that they are poorly insulated and their body mass is less so that the body stores less heat. Neonates do not shiver so that they cannot respond to a cold environment. During anaesthesia the temperature control mechanisms are depressed so that methods of maintaining body heat must be instituted. These include overhead heaters, warming blankets, warming inspired gases and fluids and covering parts of the body not being operated upon.

Other **anatomical points** are important in regional and local anaesthesia. The spinal cord and dura mater reach lower levels in neonates (L3 and S3), the iliac crests are not fully developed so that the line between them is one vertebral space lower. Fascia and aponeurosis are thinner and therefore not as easily detected when used as depth markers during nerve blocks. They can be located more easily moving the needle up and down until a scratching sensation is felt or by angling the needle so that the traverse through the layer is thicker.

An understanding of the basic sciences is helpful in optimally managing our smallest patients during anaesthesia. In the next section anaesthesia for some common operations will be considered highlighting the application aspects of basic sciences to the clinical management.

Inguinal hernia repair is a common operation in young children, especially ex-premature infants. In the latter patients the abdominal wall is weak and the normal obliteration of the sac has not occurred. The infant born prematurely has deficient iron and glycogen stores because these are laid down mainly in the last three months of pregnancy. Thus they tend to be anaemic and susceptible to hypoglycaemia unless glucose is administered. In addition, the factors which increase heat loss are exaggerated so that particular care is necessary to maintain body temperature.

There are several options for anaesthesia. **General anaesthesia** for hernia repair in infants can be used if there is no history of apnoea. Even if there is this complication can be largely avoided postoperatively if the patient is ventilated with air instead of nitrous oxide and PEEP of 2-3cm water is applied.

The use of air prevents denitrogenation of the lungs and, together with PEEP, prevents atelectasis which results in increased work of breathing and fatigue in ex-prematures and is a major cause of postoperative hypoxaemia in many patients. The anaesthetic consists of muscle relaxation, ventilation with an inhalation agent and preferably a local anaesthetic block rather than opioids so that respiratory depression is avoided.

In prematures **spinal** analgesia in advocated by some anaesthetists because there are fewer respiratory problems if they are immobilised rather than being anaesthetised. The fact that the iliac crests are level with one intervertebral space lower is fortuitous as the spinal cord also ends one space lower. A 25 needle is often used to administer bupivacaine 0.5%. An alternative is to use **caudal** anaesthesia aiming to reach at least T10.

The **ilioinguinal block** as originally described involved placing local anaesthetic under the external oblique aponeurosis thus blocking the ilioinguinal and iliohypogastric nerves as they approach the skin. This provides adequate surface anaesthesia but does not anaesthetise the area around the inguinal sac. This can be achieved by placing local anaesthetic in the layer between the internal oblique and transversus abdominis muscles. *If a short bevelled needle is available it makes it easier to feel the loss of resistance as the aponeurosis is penetrated* 1-2 cm medial to the anterior superior iliac spine depending on the size of the patient. If one is not available the aponeurosis can be located by moving the needle horizontally as it is gradually advanced until a grating or rough sensation is felt. The needle is then advanced through the aponeurosis and a pop may be felt especially with a short beveled needle. 0.25 ml/kg of 0.25% bupivacaine can be injected to produce surface analgesia. The needle is then advanced slowly with gentle pressure on the plunger of the syringe. *It is difficult to inject into* *muscle but as soon as the needle emerges into the space between them it becomes easy* to inject and a similar volume should be injected as above.

Circumcision is usually performed under light general anaesthesia with a local anaesthetic block. The reason is that under halothane alone laryngeal spasm often occurs. An understanding of the anatomy is important. **Caudal** anaesthesia is commonly used. The key points in locating the caudal canal are to feel the sacral cornua and then pull the skin cephalad (upwards) until it is just above the apex of the sacral hiatus. The needle can then be inserted just distal to the finger tip so that it passes through skin which has not been touched since being prepared with antiseptic. At this point the sacrococcygeal membrane is thickest and so more easily felt as the needle is inserted. It also enters the deepest part of the sacral epidural space and so it is not necessary to angle the needle into the canal although many people do this to ensure that they are in the correct space. 0.5 ml/kg of 0.25% bupivacaine will provide an adequate block.

The alternative is to perform a **dorsal nerve** of penis block. The skin is put on a stretch and the needle is inserted in the midline below the symphysis pubis. It is safer to angle it 10 degrees from the entry point and to advance and make injections on both sides of plain bupivacaine 0.5% 1ml + 0.1ml /kg. The needle has to penetrate the superficial fascia which can be felt with a short beveled needle or by scratching up and down as the needle is advanced until a rough sensation is felt. The fascia divides to form the suspensory ligament of the penis in the midline. This divides over the body of the penis but the nerves and blood vessels lie in the midline deep to it. It is to avoid puncturing these vessels that it is recommended to inject at an angle. As the needle is advanced under the symphysis gentle pressure on the syringe plunger will be met at first by resistance. When it becomes easy to inject the needle tip has entered a potential space which is pear shaped when filled and lies close to the nerves. Injection should be made here where it is easy to inject. The local anaesthetic diffuses easily through the fascial layer separating it from the nerves and vessels. It is important to fill this space between the symphysis and the corpora cavernosa so that the dorsal nerve and its ventral branch are both blocked as they come forward under the symphysis. The volume suggested usually achieves this.

There are some important **consequences of hypovolaemia** which may occur after trauma, burns, or as a result of post-operative bleeding such as occasionally happens after tonsillectomy. The redistribution of cardiac output, as well as its reduction has important consequences when anaesthesia is induced or analgesia is given. Students and young doctors must have the principles instilled into them because the consequences of not knowing that a greater proportion of the cardiac output goes to the brain and heart in hypovolaemia may result in dangerous myocardial or respiratory depression if depressant drugs are injected in usual doses. In addition, it is important to know that analgesics injected intramuscularly will not be effective until muscle perfusion is improved after correction of hypovolaemia .

An understanding of the application of basic sciences is important in the provision of high quality anaesthesia and care of children undergoing surgery.