The adaptations of the human placenta and foetus

Describe the adaptations of the human placenta and foetus to improve oxygen availability. (Dr P. Bush)

The human placenta is an organ located in the uterus. It plays a huge role in the active transport of nutrients and metabolic wastes across the barrier separating maternal and foetal compartments. Oxygen transport from maternal to foetal blood is a primary function of the placenta. It is incredibly important for the growth of a healthy foetus and to ensure normal foetal development. The foetus is the name given to the developing young that is also located in the uterus. Communication between the placenta and foetus is especially crucial in order to make sure intrauterine growth retardation is prevented.(Garnica AD [1] andChan WY, 1996) Variations in growth of the placenta and its vascular resistance, changes in the oxygen transfer in the placenta, and alterations in nutrient transfer and interactions between mother, placenta and foetus all have important effects on the adaptions of the foetus thought to be central to programming. Therefore future adaptions to improve placental function are likely to have lifelong health benefits for the offspring. (Keith M. Godfrey, 2002: S20-S27)

One of arguably the most important adaptions is the oxygen affinity of foetal haemoglobin. Foetal haemoglobin has an oxygen affinity times three to four times higher than that of maternal haemoglobin. In the blood supply of the placenta to the foetus, the oxygen affinity of foetal blood exceeds the affinity of the maternal blood, this hence facilitates the transfer of oxygen in the foetus. In a human pregnancy, if maternal and foetal bloods equilibrate at a PO_2 of 30mm Hg, maternal haemoglobin will be at a saturation of approximately 50%, whilst foetal haemoglobin will have achieved a saturation point of about 80%. This explains why foetal blood is always quite highly saturated even at the low PO_2 levels found in the umbilical vein. (A. M. Carter, 2009: 19-25). This means oxygen dissociates from the mothers haemoglobin and is hence transported to the foetus. Both the maternal and fetal hemoglobin have four binding sites for oxygen. The larger the quantity of binding sites that are occupied the higher the percentage saturation of oxygen. In the placenta the partial pressure of oxygen can be used to measure the even the smallest amount of dissolved oxygen. The positive correlation that occurs between the partial pressure of oxygen and the quantity of hemoglobin that is saturated is known as the oxygen dissociation curve. The shape of the oxygen dissociation curve represents the characteristics of oxygen transport. The amount of saturation in the hemoglobin changes with a change in the PO2, and due to its considerably higher affinity for oxygen the curve that is representing fetal hemoglobin shifts to the left. (McNanley T. and Woods J, 2008) This enables the foetus to have better access to oxygen from the mother’s bloodstream resulting in a more efficient development of the offspring’s respiring tissues.

Also the evolution of the beta goblin gene complex has helped to cause an increase in oxygen availability, duplication of an embryonic gene yielded HBG-T2, a gene that is expressed in the foetus and results in a higher oxygen affinity on its haemoglobin. It also results in a fatally expressed variation of haemoglobin (HBB-T3) that also has a high oxygen affinity. This means more oxygen can be bonded to each haemoglobin and transported to the foetus via the blood supply. (A. M. Carter, 2009: 19-25)

Gamma chains are adapted to have a high affinity for oxygen, this greatly aids an increase in oxygen availability The gamma chain improves oxygen availability, it is a molecule that has four principle ligands, these include oxygen, carbon dioxide, hydrogen ions and also 2, 3-diphosphogglycerate (DGP). How it works is that if one of the ligands bonds to the haemoglobin molecule it causes a decrease in the haemoglobins affinity for any of the other three ligands. This concept is known as the Bohr Effect, this is a principle that results in exchange of oxygen in the tissues being so efficient. For example if carbon dioxide bonds to a haemoglobin in the gamma chain, it decreases its affinity for oxygen and hence the oxygen is offloaded. However, at the placenta carbon dioxide is offloaded by foetal blood to maternal blood, this is known as a double Bohr Effect. Binding of hydrogen ions and DGP also reduce the gamma chains affinity for oxygen.

Adaptions that are made to the structureof the placenta can help make improvements to oxygen availability for the foetus in a number of different ways, starting with the structure of the placenta itself. The mature placenta is usually disc shaped with a radius of 9. 5cm and a thickness of 2. 5cm. The surface of the placenta that is attached to the endometrium of the uterine wall is called the basal plate and the surface nearest the foetus is called the chorionic plate. Between these two plates is a complex vascular network through which oxygen, nutrient and waste exchange is undergone. The vascular network branches out from the chronic plate, this creates a system of villi, which then terminate into terminal villi which eventually terminates into a system that contains a branched system of capillaries. The terminal villi are the smallest branches within this system and the area where the villous membrane is thinnest and hence it is here where oxygen is transferred, due to the small diffusion distance for gaseous exchange it therefore plays an important role in oxygen transfer and therefore increasing its availability to the foetus (Ahokas, R. McKinney E, 2008)

The capacity of diffusion of oxygen is directly proportional to the distance of diffusion between the placenta and the foetus. This is a contributing factor to why we are continually interested by the number of cell layers that are contained in the placenta. Placentas are always either, epitheliochorial, endotheliochorial or haemochorial, depending on a number of factors including of the trophoblast is opposed to uterine epithelium, the endothelium of the maternal vessels, or if it directly exposed to maternal blood. However it can be said that the type of placenta is really of very little functional significance in improving oxygen availability, and factors such as extensive thinning of the tissues is a lot more effective, reducing the diffusion distance between foetal and maternal blood even in a placenta which is of the epitheliochorial type. (A. M. Carter, 2009: 19-25)

The capacity of diffusion in a placenta increases with gestational age due to factors including growth and differentiation. As the villi in the placenta develop, it causes an increases in their surface areas and a decrease in their thickness. As the villi mature their blood supply improves, and their vessels adapt to become closer to the layer called the syncytiotrophoblast. Also the thinning of the villus stroma and trophoblast layer is responsible for most of the increase in diffusion, as it reduces the diffusion distance for oxygen. During gestation there is the greatest improvements to the placenta in improving diffusion to the feotus. (McNanley T. and Woods J, 2008)

The size of the placenta has a direct effect on the capacity for nutrient transfer via changes in surface area for transport. The weight of the placenta is positively correlated with birth weight. A small placenta increases nutrient transport capacity via morphological adaptations such as an increased surface area for nutrient exchange, vascularity and decreased barrier thickness. These adaptations affect placental transport capacity and the foetal to placental weight ratio.

The transfer of blood is undergone by a system known as the counter current system, it takes place in the capillaries of the placenta. It is a process in which two bloodstreams are flowing in directly opposite directions to each other. This results in a large diffusion gradient for the transfer of oxygen between the two bloodstreams, as it is transported by simple diffusion. This provides an extremely more efficient transfer of oxygen to the foetus than if the system was that of a con-current system in which two bloodstreams flow in the same direction. Also putting into consideration how oxygen transfer across the placenta only occurs by simple diffusion, a large diffusion gradient provides an extra driving force.

In conclusion, there are a number of different adaptions to the placenta and foetus that have resulted in an increase in oxygen availability. These adaptions have developed naturally over many years to improve oxygen availability to human foetuses and effectively improve their chances of survival, growth and health.

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