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"PATENT DUCTUS ARTERIOSUS" EMBRYOLOGICAL BASIS AND ITS CLINICAL SIGNIFICANCE

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ABSTRACT

Normally, in the heart of a fetus, there is a ductus arteriosus (DA) which is to close after birth at most three months. Because DA closes, it becomes ligamentum arteriosum. When DA does not close after birth, it is known as patent (open) ductus arteriosus (PDA). The left PDA occurs more than the right PDA. The size of the PDA determines the severity of the condition. Should be diagnosed and treated early in life. It can be treated either with drugs or surgery. When left untreated for a long time, it turns into Eisenmenger syndrome.

Introduction

In a normal condition, the heart of the fetus, an artery called ductus arteriosus connects the left pulmonary artery to the aorta. Normally in a developed heart, the left and right pulmonary artery carries deoxygenated blood to the lungs (pulmonary circulation), from the lungs then it carried through the pulmonary vein to the left atrium of the heart. The blood then passes through the ventricle to the aortic arch which distributes the oxygenated blood to the rest of the body (systemic circulation) [3]. In the fetal heart, there is only the systemic circulation and normally the pulmonary circulation will developed after the birth. The ductus arteriosus (DA) forms from the sixth aortic arch, and it is attached to the aorta with the first part of the pulmonary artery. In a fetus, the ductus arteries carry blood from the pulmonary artery (left) to the aorta, followed to the body. Soon after birth, the functional closure of ductus arteriosus happens due to the reflexive and hormonal contraction of the smooth muscle and forms the ligamentum arteriosum. Anatomically, the DA would close within one to three months after the birth, by the active proliferation of tunica intima [9]. When it fails to close beyond the normal duration, it is referred to as patent ductus arteriosus (PDA). PDA has caused a lot of mobility rate, and it can be an isolated abnormality or it can occur with other heart defects like coarctation of the aorta and transposition of the great vessels. PDA is asymptomatic in babies when the opening is small but can be diagnosed by examination. A continuous machine-like murmur can be heard at the left infraclavicular part. The murmur radiates along the pulmonary arteries and is well heard over the left back side. Patent Ductus Arteriosus was classified on basis of angiogram appearance. Recently, the PDA is classified based on the size of angiogram by Krichenko in 1989 and hemodynamic sound.

Based on the clinical classification, the blood from the descending arch of aorta would flow into the left pulmonary artery due to pressure.

Incidence

Patent ductus arteriosus (PDA) is one of the most commonly happening abnormalities, especially in infants. A few cases can be seen in adults. Congenital anomalies are the causes of death in infants under one year of age [1]. The incidence of patent ductus arteriosus in children born at full term are 0.02% and 0.006% of life birth. This incidence increases in children born prematurely (20% of infants born at 32 weeks of gestation and 60% of infants born before 28 weeks of gestation) and infants born at high altitudes. A low birth weight infant (weight less than 2500g) also has a high tendency of developing PDA. As an isolated abnormality, patent arteriosus represents 5-10% of all congenital heart abnormality. It occurs in approximately 0.008% of live premature births. There is no data support to a particular race. If it is an isolated PDA, the incidence of female to male is ratio 2:1 respectively. In cases where patent ductus arteriosus is associated with another teratogenic exposure such as rubella, the incidence between female to male is equal [6, 5, 8].

Ontogenesis for normal derivatives of the branchial arches

In the fourth week of development of the embryo, the distal part of the truncus arteriosus (aortic sac) receives its own artery. They are not all present at once in the pharyngeal arch (Fig 1A). There are six pairs of aortic arch arteries (where the fifth artery never develops or incompletely develops and then regresses). Accordingly, the six arteries are numbered I, II, III, IV, V and VI. As development continues, some arteries completely regress. The truncus arteriosus divides the outflow of the heart into the dorsal aorta and the pulmonary trunk. The aortic sac forms right and left horns, which later gives rise to brachiocephalic artery and the proximal segment of the aortic arch (Fig 1B, 2A & 2B). On day 27, the first aortic arch partially disappears, though a small part continues to form the maxillary artery.

Also, the second aortic arch partially disappears. The remaining parts of the second aorta are hyoid and stapedial arteries. The third aortic arch is large. Both fourth and sixth aortic arches are in the process of formation. Even though the sixth arch is yet to be completed, the primitive pulmonary artery is present as a major branch. On day 29, the first and second aortic arches have completely disappeared. The third, fourth and sixth arches are large. The conotruncal region has divided so that the sixth arches persist with the pulmonary trunk. With further development, the original symmetrical form of the aortic arch is lost and the definitive pattern is established. This representation may clarify the conversion from the embryonic to the adult arterial system.

The common carotid artery and the first part of internal and external carotid artery are formed from the third aortic arch. Between the left common carotid and left subclavian arteries, part of the arch of aorta is formed by the fourth aortic arch. Also on the right side, the proximal segment of the right subclavian artery, distal part which is formed by the right dorsal aorta and the seventh intersegmental artery. The proximal segment of the right pulmonary artery is branched from the sixth pulmonary aortic arch. The connection between the distal part of this arch on the right and the dorsal aorta is lost and it soon disappears. The distal part on the left continues during intrauterine life as ductus arteriosus [9].

Soon after birth, the functional closure of ductus arteriosus happens due to the reflexive and hormonal contraction of the smooth muscle and forms the ligamentum arteriosum. Anatomically, the DA would close within one to three months after the birth, by the active proliferation of tunica intima [9].

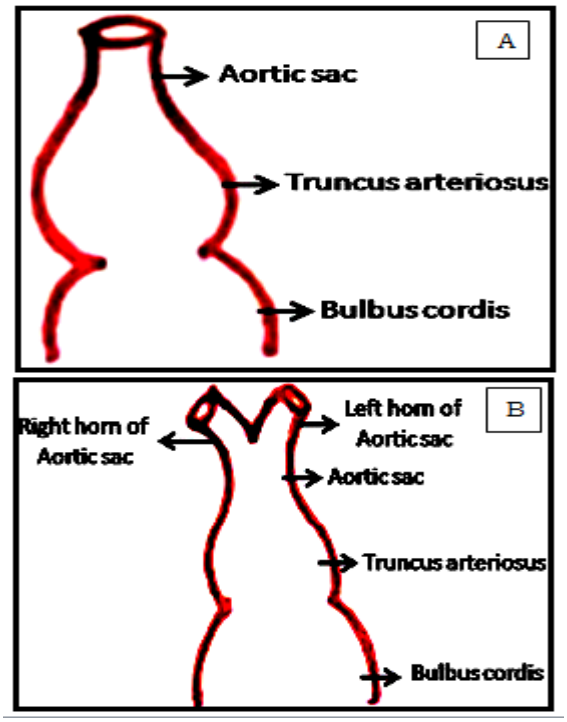

Fig 1: The schematic shows the development of Aortic sacs A. schematics showing the proximal part of the developing heart tube and B. During the later period, the Aortic sac shows its terminal branches called Right and Left horns [2].

When the baby is born, the fluid in the lungs comes out when the baby cries and breathes in. Now pulmonary circulation and systemic circulation occurs. Due to pulmonary circulation, DA closes because of the increase in oxygen or the reduction in prostaglandins (which was gotten from the maternal blood through the placenta) or due to decreased pulmonary vascular resistance [5].

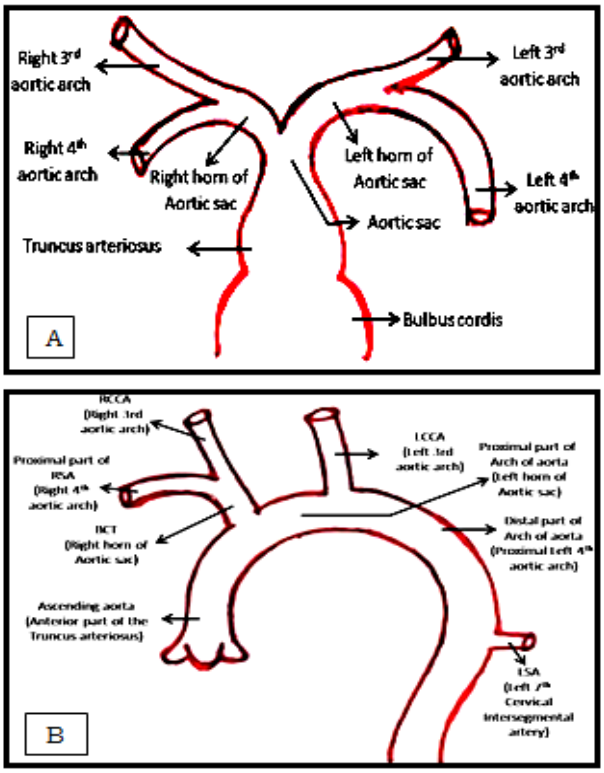

Fig 2: The derivatives of aortic arch arteries A. schematics showing the Truncus arteriosus receives the third (III) and fourth (IV) right and left Aortic arch arteries, which opens into the right and left horns of the Aortic sac and B. Derivatives of the Aortic sac horns and third (III) and fourth (IV) right and left Aortic arch arteries.(BCT-Brachiocephalic trunk, RSA- Right subclavian artery, RCCA- Right Common carotid artery, LCCA- Left Common carotid artery and LSA-Right subclavian artery) [2].

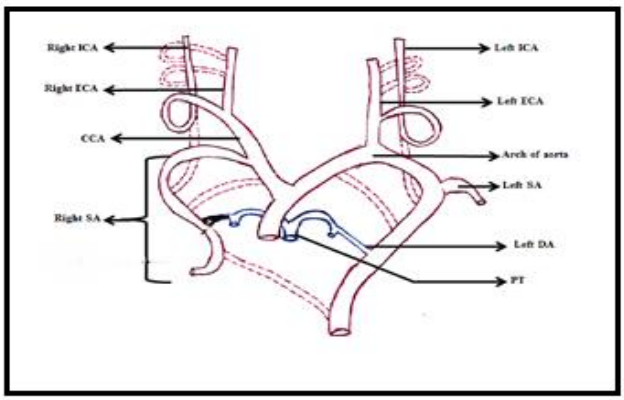

Fig 3: The derivatives of aortic arch arteries. Schematics showing the Truncus arteriosus receives the third (III), fourth (IV) and sixth (XI) right and left Aortic arch arteries. Broken lines are aortic arch arteries that have disappeared. Origin of left subclavian artery is at descending aorta. (ICA- Internal carotid artery, ECA-External carotid artery, CCA-Common carotid artery, SA- Subclavian artery, DA- Ductus arteriosus, PT-Pulmonary trunk).

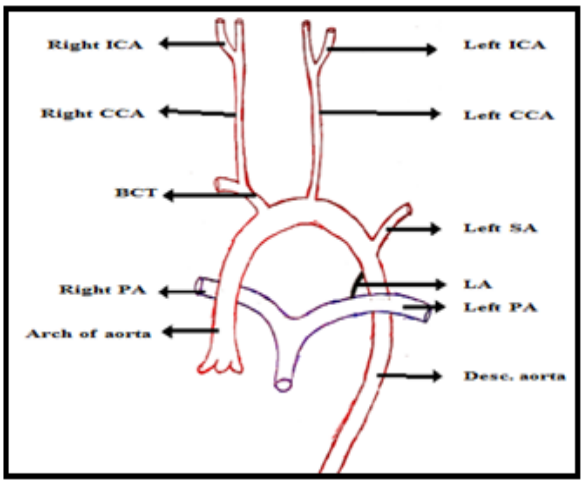

Fig 4: The derivatives of aortic arch arteries. Schematics showing the great arteries in adults. The left SA is in the arch of aorta. Compare left SA in fig-4 and fig-5. Ligamentum arteriosum formation between the left PA and the arch of aorta just below the left subclavian artery. (ICA- Internal carotid artery, CCA-Common carotid artery, BCT- Brachiocephalic trunk, SA- Subclavian artery, LA- Ligamentum arteriosum, PA- Pulmonary artery, Desc. Aorta- Descending aorta).

Ontogenesis for the right and left "Patent Ductus Arteriosus"

In the normal embryonic development, pulmonary arteries are a branch of the sixth arch. During the early period, the ductus arteriosus connects the left pulmonary artery to the arch of aorta below the level of left subclavian artery and the right pulmonary artery connects to the dorsal part of the aorta. Normally, soon after birth, the functional closure of ductus arteriosus (DA) happens due to the reflexive and hormonal contraction of the smooth muscle and forms the ligamentum arteriosum. Anatomically, the DA would close within one to three months after the birth, by the active proliferation of tunica intima [9] and forms the ligamentum arteriosum (Fig-4). Normally, the right ductus arteriosus disappears in the early embryonic life and it regressed even before birth.

In some cases, where the ductus arteriosus persists on the right side, this abnormality is life threatening. This DA connects the right pulmonary artery and the right subclavian artery. The right subclavian artery is made up of;

- 7th cervical intersegmental artery
- Dorsal aorta between the 7^{th} cervical intersegmental artery and fourth aortic arch artery
- Right fourth aortic arch artery

The blood supply of a normal fetus is the flow of blood from the arch of aorta which then distributes to every part of the body with the help of some arteries. One of these arteries include the right subclavian artery (a branch of brachiocephalic trunk which is a division in the arch of aorta). The right vertebral artery joins with left vertebral artery to form basilar artery and then forms posterior cerebral artery. These arteries supply the cranial meninges, cerebellum, brain stem, cerebrum, inferior aspect of cerebral hemisphere, occipital lobe, optic tract, cerebral peduncle, inferior capsule and thalamus [4]. So, the blood supply in an infant with abnormal right ductus arteriosus is from the arch of aorta to the brachiocephalic trunk to the right subclavian artery which then flows back into the right pulmonary artery due to high pressure of blood from the aorta to respective parts of the body (Fig-6).

As a result of the flow of blood from the right subclavian artery to the right pulmonary artery, the amount of blood flow to the brain and the arm is reduced. The reduced blood supply to the brain is known as ischemia thereby causing the death of tissues in the brain. This can cause stroke or irreversible brain damage. The brain cannot complete aerobic metabolism during brain ischemia, so the brain is unable to switch to anaerobic metabolism and because the brain does not have any energy stored in it, ATP level rapidly drop within four minutes. The ability for cells to maintain electrochemical gradients is lost. The disruption of blood flow to the brain for ten seconds can cause instant loss of consciousness. The disruption of blood flow for twenty seconds can cause electrical activities to stop.

In cases where ductus arteriosus persists on the left side, this could be life saving or life threatening. This DA connects the left pulmonary artery to the arch of aorta. The blood supply in a child with PDA is from the aorta to the left pulmonary artery (left to right shunt) (Fig-6). Some of the reasons why DA doesn't close include;

- Lungs that are not fully developed due to preterm birth. It is still a misery on how to manage a preterm with PDA.
- High level of prostaglandins in the fetal circulation or increase sensitivity to prostaglandins.
- Low birth weight in preterm babies
- Delivery in high altitude

This is not related but the chances are high. This is when a mother is infected with rubella (a type of measles). This mechanism is not fully understood. There is general agreement that isolated PDA should be closed as early in life, however maintenance of ductal patency (by administering prostaglandin E) can be lifesaving when PDA is the only means to sustain systemic or pulmonary blood flow (e.g., aortic or pulmonic atresia present in infants) [5].

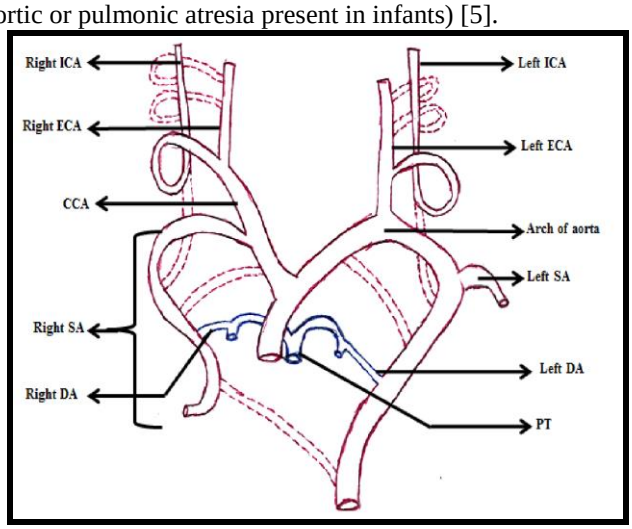

Fig 5: The derivatives of aortic arch arteries. Schematics showing the persistency of ductus arteriosus on the left and right side respectively. (ICA- Internal carotid artery, ECA- External carotid artery, CCA-Common carotid artery, SA- Subclavian artery, DA- Ductus arteriosus, PT- Pulmonary trunk).

PDA has clinical classifications. According to Krichenko in 1989, PDA is classified on the basis of angiogram appearance. These classifications affect the flow of blood (that is the wider the DA, the more flow of blood). The classifications include;

TYPE - A:

This is a conical duct. There is a well well-defined aortic ampulla with a constriction at the end of the pulmonary artery.

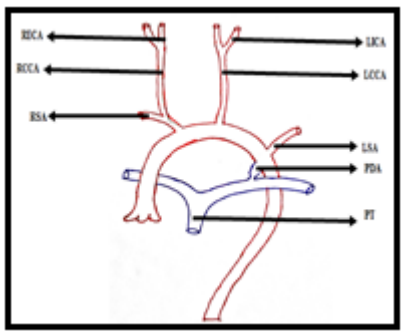

Fig 6: The derivatives of aortic arch arteries. Schematics showing the persistency of conical ductus arteriosus on the left side. (LICA- Left internal carotid artery, RECA- Right external carotid artery, LCCA-Left common carotid artery, RCCA-Right common carotid artery, LSA-Left subclavian artery, RSA-Right subclavian artery, PDA-Patent ductus arteriosus, PT- Pulmonary trunk).

TYPE - B

This is a large duct. There is a window like structure that is very short in length.

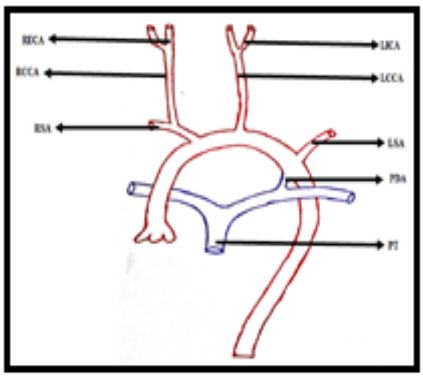

Fig 7: The derivatives of aortic arch arteries. Schematics showing the persistency of large ductus arteriosus on the left side. (LICA- Left internal carotid artery, RECA- Right external carotid artery, LCCA-Left common carotid artery, RCCA-Right common carotid artery, LSA-Left subclavian artery, RSA-Right subclavian artery, PDA-Patent ductus arteriosus, PT- Pulmonary trunk).

TYPE . C

This is a tubular duct. There are no constrictions.

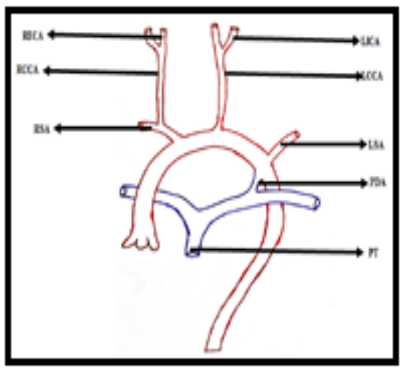

Fig 8: The derivatives of aortic arch arteries. Schematics showing the persistency of tubular ductus arteriosus on the left side. (LICA- Left internal carotid artery, RECA- Right external carotid artery, LCCA-Left common carotid artery, RCCA-Right common carotid artery, LSA-Left subclavian artery, RSA-Right subclavian artery, PDA-Patent ductus arteriosus, PT- Pulmonary trunk).

TYPE - D

This is a complex duct. There are multiple constrictions.

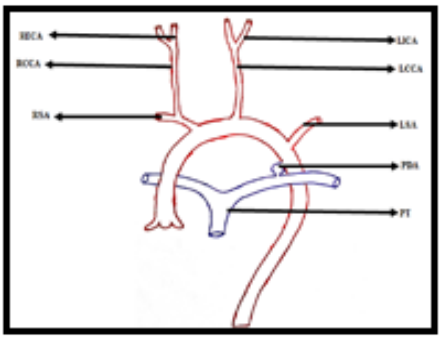

Fig 9: The derivatives of aortic arch arteries. Schematics showing the persistency of complex ductus arteriosus on the left side. (LICA- Left internal carotid artery, RECA-Right external carotid artery, LCCA-Left common carotid artery, RCCA-Right common carotid artery, LSA-Left subclavian artery, RSA-Right subclavian artery, PDA-Patent ductus arteriosus, PT- Pulmonary trunk).

TYPE - E

This is an elongated duct. There is a remote constriction at the pulmonary artery.

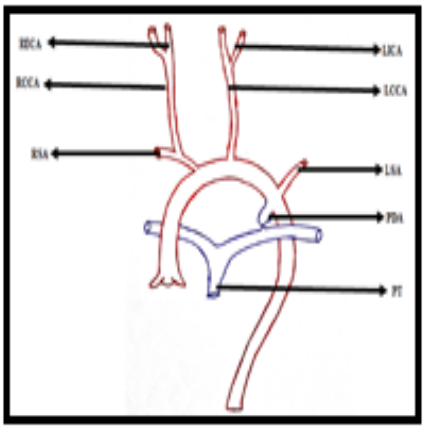

Fig 10: The derivatives of aortic arch arteries. Schematics showing the persistency of elongated ductus arteriosus on the left side. (LICA- Left internal carotid artery, RECA-Right external carotid artery, LCCA-Left common carotid artery, RCCA-Right common carotid artery, LSA-Left subclavian artery, RSA-Right subclavian artery, PDA-Patent ductus arteriosus, PT- Pulmonary trunk)

Recently, the classification is based on angiographic size and hemodynamic sound [3].

Type	Size	Hemodynamics
Silent PDA	Less than 1.5mm	Absence of PDA murmur
Very small PDA	Less than 1.5mm	Presence of PDA murmur
Small PDA	1.5mm to 3.0mm	Presence of PDA murmur
Moderate PDA	3.0mm to 5.0mm	Presence of PDA murmur
Large PDA	Greater than 5.0mm	Presence of PDA murmur

Discussion

There is a great variation with patients with PDA, though most are diagnosed with infants. In some cases, there might be delay in the diagnosis of PDA until the patient has grown

older or is an adult. Left to right shunting is a common sign and symptom in isolated patent ductus arteriosus. PVR (pulmonary vascular resistance) and an open ductus arteriosus determines the volume of the shunt [3] (a passage that allows the movement of fluid from one part to another part of the body) [10 -19]. During diagnosis, the existence of PDA and other cardiac anomalies should be put into consideration. For survival of newborns with severe obstructive lesions to left or right side of the heart, diagnosis is usually serious.

In fetal life, left DA is a normal structure that allows the flow of blood leaving the right ventricle to pass to the descending aorta. From the sixth week, DA is responsible for right ventricular outflow and contributes 60% of cardiac output throughout fetal life. About 10% of blood from the right ventricle passes the pulmonary bed. Ductus arteriosus is conical in shape. PDA is a left aortic residue, though it can occur on both left and right sides. Left DA is normal in a fetus but right DA is an abnormality and is usually associated with other cardiovascular abnormalities. Krichenko classification of patent ductus arteriosus is based on angiography which includes type A (fig-6), type B (fig-7), type C (fig-8), type D (fig-9) and type E (fig-10) PDAs. These classifications can be seen in either right or left PDA. With these classifications, the severity of this defect can be determined. The presence of complex congenital heart defects can cause the absence of the anatomy of DA. Structurally, the aorta, pulmonary artery and carotid artery are mistaken for PDA during surgical procedures.

The closure of DA before birth can cause right heart failure. The use of nonsteroidal anti-inflammatory drugs (NSAIDs) such as ibuprofen, naproxen etc. can cause the closure of DA (this is because these NSAIDs block prostaglandins formation). Normally in a fetus, the level of oxygen is low because the fetus gets the required oxygen and nutrients needed from the mother through the placenta and with the high level of prostaglandins in the fetal circulation, DA is kept open. At birth, the placenta is removed thereby destroying the main source of production for prostaglandin. The lungs expand and normal respiration begins. The level of oxygen in the blood increases and PVR decreases. In normal closure of DA, there is an unexpected contraction of the muscular walls in the ductus arteriosus which increases the pressure of oxygen. These happen the same time. If SVR (systemic vascular resistance) is not more than PVR, blood flow from the aorta through the ductus arteriosus into the pulmonary artery would occur. In the 1940s, many tests have been done to know the real reason behind the closure or opening of DA. The actual reason for the closure or opening of DA involves the manipulation of the chemical mediators, autonomic nervous system and ductal musculature. Vascular tone of DA can be determined by the cause of relaxation which include, (i) High level of prostaglandins, (ii) Production of nitric oxide in ductus arteriosus and (iii) Reduced level of oxygen. Vascular tone of DA can be determined by the cause of contraction which include, (i) Reduced level of prostaglandins, (ii) Norepinephrine, (iii) Decreased prostaglandin-E receptors, (iv) Increase sensitivity to prostaglandins and (v) Acetylcholine.

The closure of DA in full-term infants is very rare. If PDA is left untreated for a long time, it can develop into Eisenmenger syndrome and can change from left to right shunt to right to left shunt. In this case, PDAs closure is not advisable. The only way of treatment is with a lung transplant [3].

In both right and left PDA, blood flows into the right and left pulmonary arteries from the right and left subclavian arteries (this is due to pressure) respectively. This reduces the amount of deoxygenated blood and increasing the amount of oxygenated blood going to the lungs thereby causing problems for the respiratory system and dysfunctional lungs. The muscles in the heart now pump blood harder than before to ensure the flow of blood to every part of the body.

When the muscles persist with pumping blood with more pressure, they enlarge thereby causing the heart to enlarge.

With right sided PDA, there's reduced flow of blood to the brain (ischemia), posterior cerebral circulation, posterior neck, upper limbs and the superior and the anterior chest wall. This is really dangerous (because it is right to left shunting) if not attended to with urgency. It can destroy the brain tissues due to necrosis and if no medical precaution is taken, this can cause death. With the knowledge about right patent ductus arteriosus, if it is an isolated condition to cause the death of the baby few months after birth. If this condition is diagnosed minutes or hours after birth, then one of the treatments required for the closure a patent ductus arteriosus whether with drugs or surgery should be done without delay to prevent the death of the child.

With left sided PDA, there's reduced flow of blood to abdominal organs and lower extremities. The organs can become dysfunctional due to lack of oxygen. With the lower extremities, there would be cell death. If left for a long time without oxygen, the limbs become numb and progressively there would be permanent damage of the nerves that are responsible for sensory and motor impulses. PDA can be detected by auscultation for murmurs and a wider pulse pressure due to the increase in systolic (contraction) pressure.
Some medications can be used for the treatment of patent ductus arteriosus like the NSAIDs (these drugs inhibit prostaglandins) such as ibuprofen, naproxen etc. The surgical treatments like PDA ligation (tying the beginning and the end of DA which cause the muscle cells to deteriorate with time due to no blood supply) and coil occlusion (insertion of a coil into the ductus arteriosus thereby stopping blood to flow through it) are maybe necessary sometimes.

Conclusion

In every delivery, careful auscultation should be done on the child on both right and left sides. The physician should listen for any murmurs due to blood flow through the wrong side of the heart. A follow up should be done with the child for the first three months of life (this is the duration of time ductus arteriosus is to close anatomically). If DA is still patent for about six months after birth, treatment can be started. Note that for right PDA, treatment should be done immediately after birth because it is not supposed to be open till birth. Right PDA cannot occur in adults due to the fact that it can lead to death if not treated with urgency. After treatment, physicians should follow up with their patients to ensure that there are no complications with the treatment being used by them.

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