The Umbilical Cord

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Glossary

Allantois	primitive excretory duct
Cord prolapse	passage of the umbilical cord through the cervix prior to delivery of the infant
Funisitis	inflammatory cell infiltrate in the umbilical vessels walls and Wharton's jelly
Insertion	point at which the umbilical cord attaches to the placenta
Meckel's diverticulum	persistent outpouching of bowel contents through the abdominal wall at the umbilicus
Omphalomesenteric duct remnant	remains of the yolk sac stalk within the proximal portion of the umbilical cord
Vasa previa	umbilical cord vessels, usually in a case of a velamentous insertion, which are overlying the internal cervical os
Velamentous	insertion of the umbilical cord into the external membranes

Wharton's jelly	proteoglycan rich matrix in which the umbilical vessels are embedded
Yolk sac	outpouching of the endoderm which serves as the site of initial blood cell formation

I. Introduction

The umbilical cord is the lifeline between the fetus and placenta. It is formed by the fifth week of development and it functions throughout pregnancy to protect the vessels that travel between the fetus and the placenta. Compromise of the fetal blood flow through the umbilical cord vessels can have serious deleterious effects on the health of the fetus and newborn.

II. Formation and structure of the umbilical cord

By the end of the third week of development the embryo is attached to placenta via a connecting stalk (Figure 1). At approximately 25 days the yolk sac forms and by 28 days at the level of the anterior wall of the embryo, the yolk sac is pinched down to a vitelline duct, which is surrounded by a primitive umbilical ring (Figure 2A). By the end of the 5th week the primitive umbilical ring contains 1) a connecting stalk within which passes the allantois (primitive excretory duct), two umbilical arteries and one vein; 2) the vitelline duct (yolk sac stalk); and 3) a canal which connects the intra- and extraembryonic coelomic cavities (Figure 2C). By the 10th week the gastrointestinal tract has developed and protrudes through the umbilical ring to form a physiologically normal herniation into the umbilical cord (Figures 2B, D and 3). Normally these loops of bowel retract by the end of the third month. Occasionally residual portions of the vitelline and allantoic ducts, and their associated vessels, can still be seen even in term umbilical cords, especially if the fetal end of the cord is examined (Figure 4).
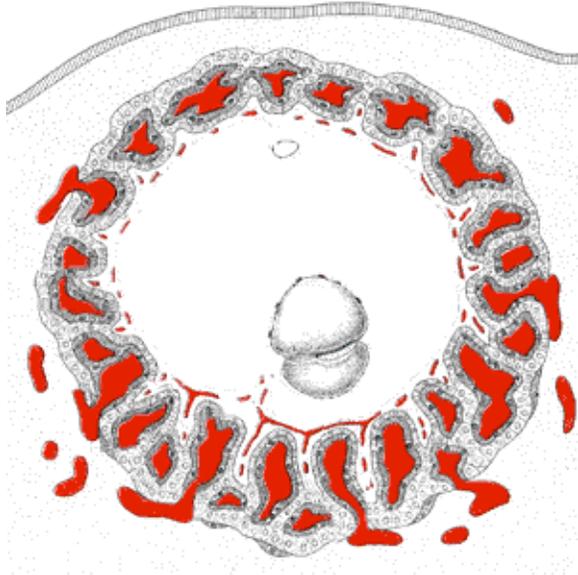
Figure 1. Beginning of the umbilical cord. By 21 days the embryo has begun to separate from the developing placenta by a connecting stalk. Within this stalk are the beginnings of the early circulatory system. (Modified from Sadler TW, Langman's Medical Embryology, 5th edition, Williams & Wilkins, 1985, with permission.)
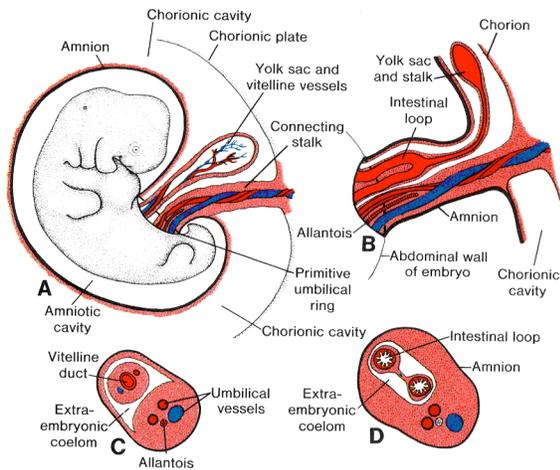

Figure 2. Contents and development of the umbilical cord. A, C: At 5 weeks of developing the embryo is connected to the placenta by a stalk which contains the umbilical vessels and allantois. Adjacent to this stalk is the yolk sac stalk which consists of the vitelline duct (yolk sac duct) and the vitelline vessels. These structures all pass through the primitive umbilical ring. B, D: By 10 weeks of development the yolk sac duct has been replaced by loops of bowel within the umbilical cord. These will normally regress back into the peritoneal cavity by the end of the third month. (From Sadler TW, Langman's Medical Embryology, 5th edition, Williams & Wilkins, 1985, with permission.)
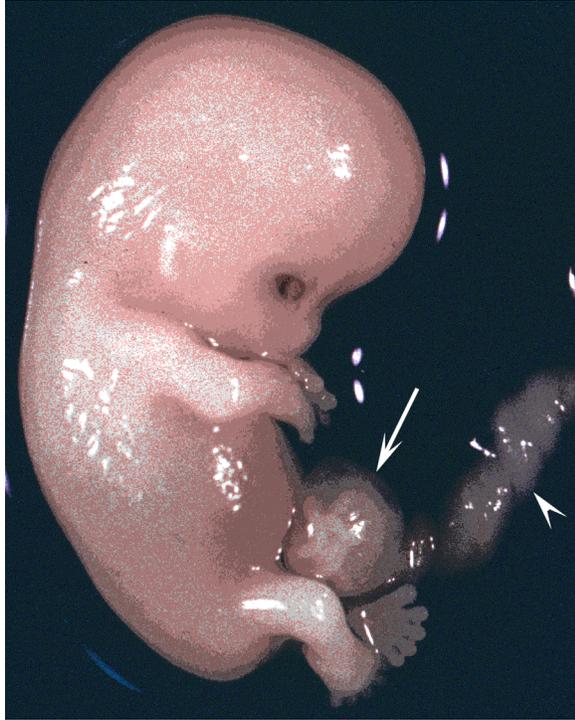
Figure 3. Fetus at ~53 days post-ovulation (21.5 mm crown-rump length) showing distinct intestinal herniation into proximal umbilical cord (arrow). Note twisting of umbilical cord (arrow head).
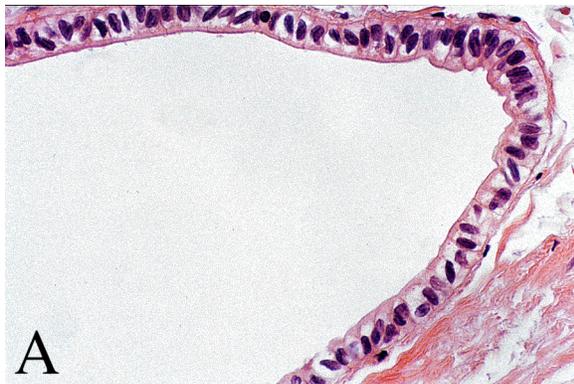

Figure 4. Remnants of the yolk sac stalk (A) and the allantois (B) can often be identified, especially near the fetal end of the cord. A) A cross section of yolk sac stalk (omphalomesenteric duct remnant) reveals a vacuolated, mucin rich epithelium, similar to normal intestinal epithelium. B) Cross section of an allantoic remnant reveals a flattened squamous epithelium similar to the urothelium found in the urogenital system.

The umbilical cord normally contains two umbilical arteries and one umbilical vein. These are embedded within a loose, proteoglycan rich matrix known as Wharton's jelly (Figure 5). This jelly has physical properties much like a polyurethane pillow, which—if you have ever tried twisting such a pillow you know—is resistent to twisting and compression. This property serves to protect the critical vascular lifeline between the placenta and fetus (Figure 6).
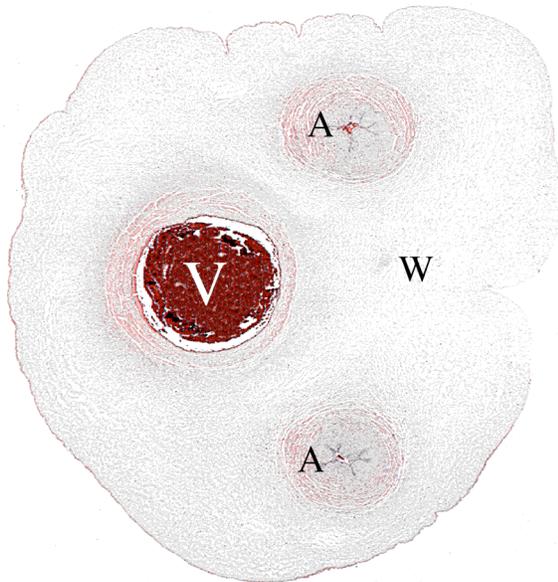

Figure 5. Cross section of normal umbilical cord. Embedded within a spongy, proteoglycan rich matrix know as Wharton's jelly (W) are normally two arteries (A) and one vein (V).
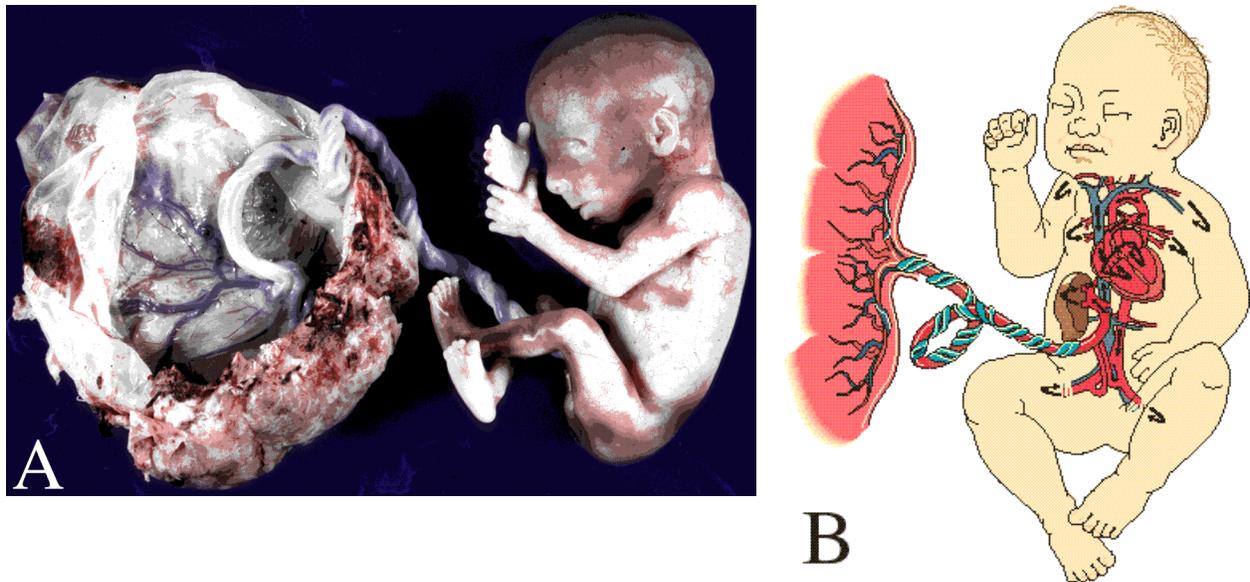
Figure 6. The umbilical cord protects the fetal vessels that connect the placenta and fetus. A) Fetus and placenta from a 17 week gestation. B) Diagram of the circulation within the fetus, umbilical cord and placenta.

III. Abnormal umbilical cord development

Approximately 1% of all umbilical cords contain only one artery—rather than the normal two. Although many infants born with a single umbilical artery have no obvious anomalies, single umbilical artery has been associated with cardiovascular anomalies in 15-20% of such cases. While these anomalies could be the result of genetic factors alone, environmental factors may also play a part. For example, Naeye has shown an association between a single umbilical artery and maternal smoking during pregnancy.

As was stated previously, loops of bowel can be found within the proximal portion of the cord up until the end of the third month (Figures 2 and 3). When this regression does not take place and herniation of peritoneal contents persists to term, a condition known as Meckel's diverticulum exists. Occasionally only a small portion of the vitelline duct may persist to term, leading to a vitelline cyst or fistula, which may need to be surgically removed after birth.

IV. Pathologic processes affecting the umbilical cord

As with any organ or tissue, the umbilical cord can be subjected to both intrinsic and extrinsic pathological processes. Intrinsic processes include inflammation, knots and torsion, while extrinsic damage can occur iatrogenically following invasive, diagnostic procedures.

The most common pathological finding in the umbilical cord is funisitis (from the Latin "cord inflammation"). Funisitis is the result of neutrophils being chemotactically activated to migrate out of the fetal circulation towards the bacterially infected amnionic fluid (Figure 7). Since the ability of neutrophils to respond to chemokines and endotoxin is dependent on cellular maturation, it is not surprising to note that funisitis is only seen commonly after 20 weeks of gestation.
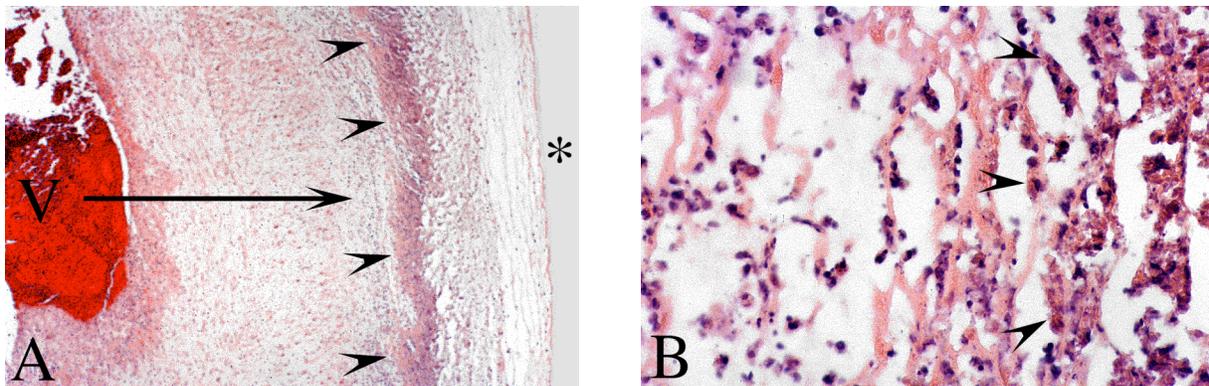

Figure 7. Fetal neutrophil migration through the umbilical cord (funisitis). A) In the presence of bacterial growth within the amnionic fluid (*), fetal neutrophils leave the umbilical vessels (V) and migrate towards the amnionic cavity (arrow). In this case of severe funisitis, a wave of neutrophils and neutrophil breakdown products can be seen (arrow heads). B) Higher magnification of the edge of the neutrophil wave (arrow heads).

Less commonly, but with potentially devastating consequences, the umbilical cord can become knotted (Figure 8). If the knot is loose, fetal circulation is maintained. However, if the knot is tightened, for example at the time of fetal descent through the birth canal, the tightening knot can occlude the circulation between the placenta and fetus, resulting in an intrauterine demise. The Wharton's jelly surrounding the fetal vessels is capable of withstanding significant torsional and compressional forces, as shown in Figure 9. Occasionally, however, Wharton's jelly does not develop in all portions of the cord. When this occurs, the fetal vessels are no longer protected from

torsional forces and they can become occluded if twisted sufficiently (Figure 10), again leading to an intrauterine demise.

Figure 8. True knot in an umbilical cord (arrow). If loose, a true knot will not lead to fetal compromise. However, if the knot tightens—for example at the time of delivery—fetal blood flow through the umbilical cord vessels can become occluded, leading to fetal demise.
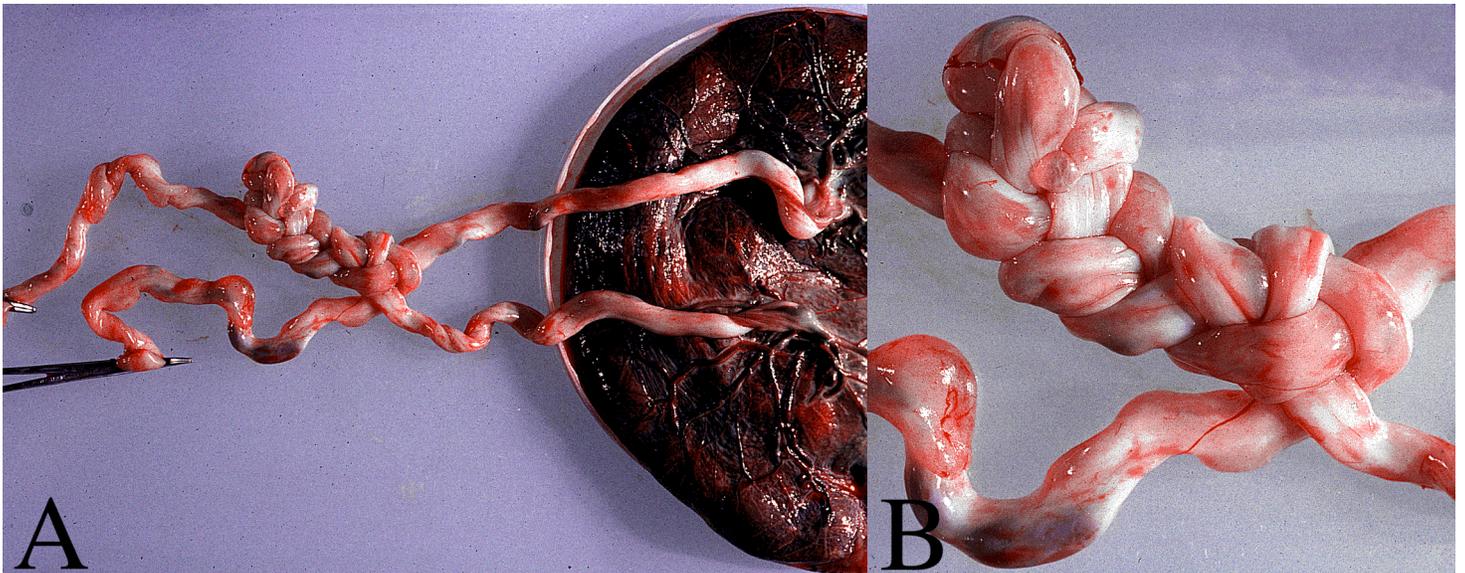

Figure 9. Umbilical cord braiding in a monochorionic-monoamnionic twin placenta at 34 weeks gestation. A) This braid was diagnosed by ultrasound at approximately 32 weeks. The fetuses were monitored continuously and when they showed signs of stress were delivered successfully by emergency Cesarean section. B) Closer examination of the braided umbilical cord shows that in spite of the marked compression of the Wharton's jelly, the fetal vessels were still protected from complete occlusion.
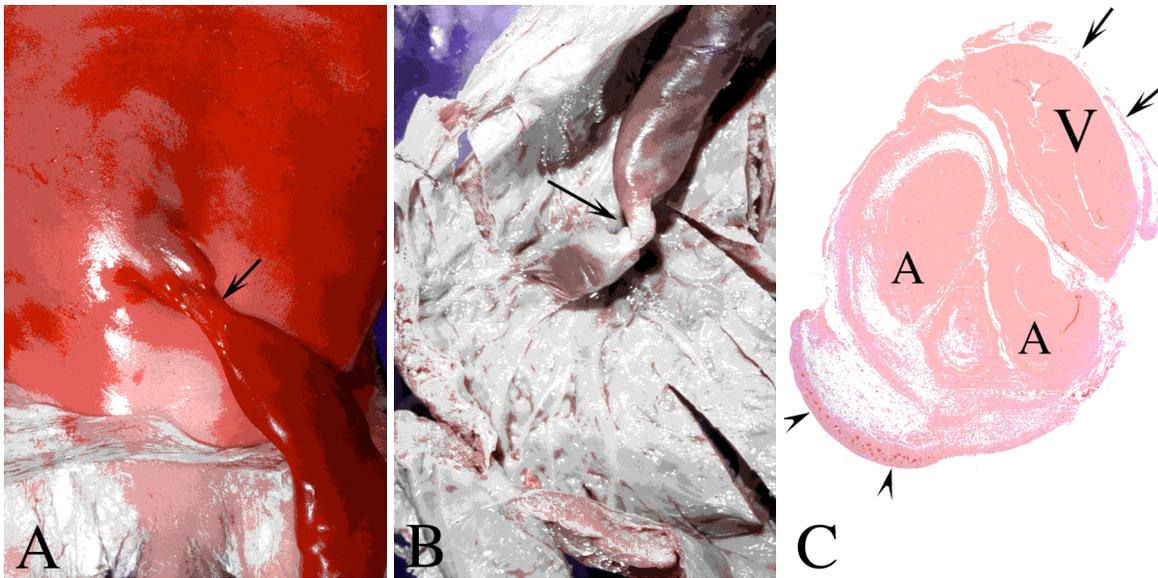
Figure 10. Loss of Wharton's jelly. A) The cause of this second trimester intrauterine fetal demise was loss of Wharton's jelly near the fetal insertion (arrow). B) Although loss of Wharton's jelly is most often seen near the fetal insertion, occasionally loss and subsequent torsion of the fetal vessels can occur near the placental insertion point (arrow). C) Cross section of umbilical cord at fetal insertion with marked loss of Wharton's jelly. The umbilical arteries (A) and vein (V) have little protective matrix beyond their vascular walls (arrows), making these vessels—especially the vein—susceptible to compression. Note the fetal epidermal vessels at one edge of the tissue section (arrow heads).

V. Umbilical cord length and twisting

Analogous to how a kitchen phone cord becomes longer with increased use, umbilical cord length is dependent on fetal movements–the more movement, the longer the cord. The converse is also true–less intrauterine movement leads to shorter umbilical cords (as attested to by animal experiments where induced fetal muscle paralysis led to shortened umbilical cord length). Normally, the human umbilical cord reaches a length of 60-70 cm at term. Although the length of the umbilical cord has no intrinsic effect on fetal blood flow, a longer cord is more susceptible to knotting, entanglement around the fetus (especially the neck), and even prolapse out of the uterus during delivery (Figure 11), any of which can lead to intrauterine fetal demise.
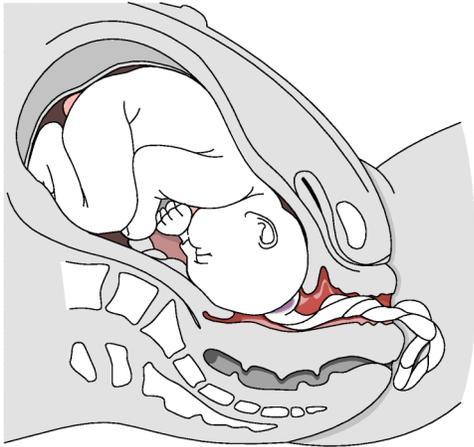
Figure 11. Umbilical cord prolapse. During delivery the umbilical cord, especially if excessively long, may deliver prior to the fetus. Folding and compression of the umbilical cord can lead to fetal stress and in some case, fetal demise.

An intriguing association between umbilical cord length and mental and motor development has been suggested by Naeye. As part of the Collaborative Perinatal Study, Naeye correlated 35,799 umbilical cord lengths with clinical, demographic and social data. He found that decreased cord length was correlated with decreased IQ and a greater frequency of motor abnormalities. Very long cords, on the other hand, were associated with abnormal behavior control and hyperactive behavior.

Intrauterine movement, in addition to controlling umbilical cord length, also appears to control cord twisting. Cord twisting can be seen as early as the 6th week and is well established by the 9th week of development. One might imagine that the umbilical cord twist—either counterclockwise (left) or clockwise (right)—might be random, but left twisting outnumbers right by a ratio of approximately 7:1 (or in other words, ~85% are left, while 15% are right twisted). Since this ratio is similar to the ratio for right to left handedness (approximately 15% of the population is left handed), some authors have suggested that handedness may be the determining factor for umbilical cord twisting. This has proven not to be true, however. What is clear, nevertheless, is that the degree of twisting does relate to intrauterine movement and as with short umbilical cords, cords with little twisting are associated more frequently with compromised fetuses. Finally, hypertwisting can lead to intrauterine fetal demise by compressing the fetal vessels beyond the capacity of the Wharton's jelly to protect them (Figure 12).
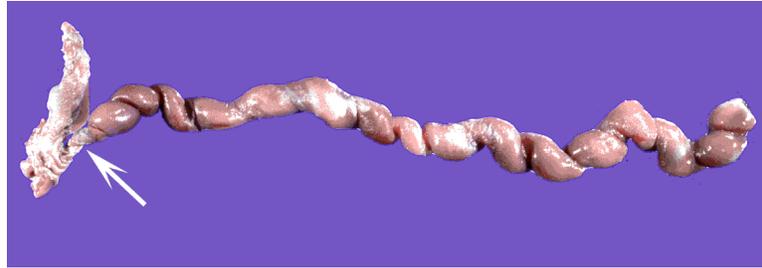
Figure 12. Hypertwisted umbilical cord. Umbilical cord from an intrauterine fetal demise in which the cord has been markedly twisted. Note the decreased Wharton's jelly at the fetal insertion point (arrow).

VI. Umbilical cord insertion

The umbilical cord normally inserts near the center of the placenta (see Figure 8). However, in approximately 7% of single births the insertion point occurs at the very edge of the placenta (marginal insertion) and in about 1% of cases, the umbilical cord does not insert into the placenta at all, but the fetal vessels ramify through the external membranes before entering the placenta (velamentous insertion). When the umbilical cord inserts into the chorionic plate of the placenta (Figure 13), the fetal vessels are stabilized, and thus protected from torsional and shear forces. On the other hand, insertion into the membranes exposes the fetal vessels to the potential for rupture due to shearing forces (Figure 14) or if the vessels pass near the internal cervical os (vasa previa), by rupture due to an ascending inflammation prior to the time of delivery (Figure 15).
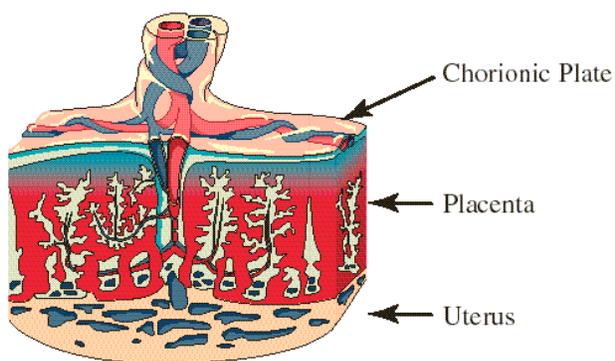

Figure 13. Insertion of umbilical cord into chorionic plate. Normally the umbilical cord inserts near the center of the chorionic plate, which stabilizes the fetal vessels as they leave the umbilical cord. Like the roots of a tree, the fetal vessels branch over the surface of the chorionic plate and then dive into the placental parenchyma.
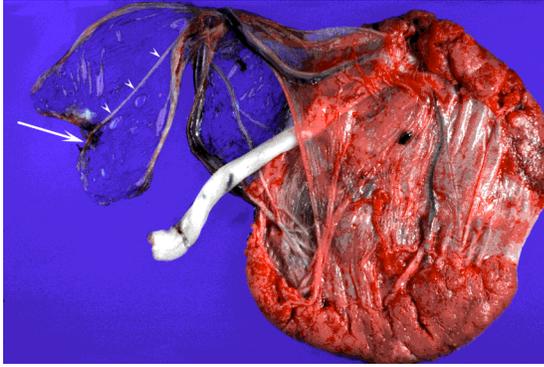
Figure 14. Rupture of a fetal vessel within the external membranes. The umbilical cord of this placenta inserted at the placental margin. The fetal vessels emanating from the insertion point did not traverse into the placenta, as is the usual case, but instead traveled through portions of the external membranes (arrow heads). This velamentous vessel, overlying the cervical os (vasa previa), was inadvertently ruptured at the time of delivery. Although the fetus lost a significant amount of blood, it survived and did well due to the rapid delivery by the obstetrician following the vascular rupture.
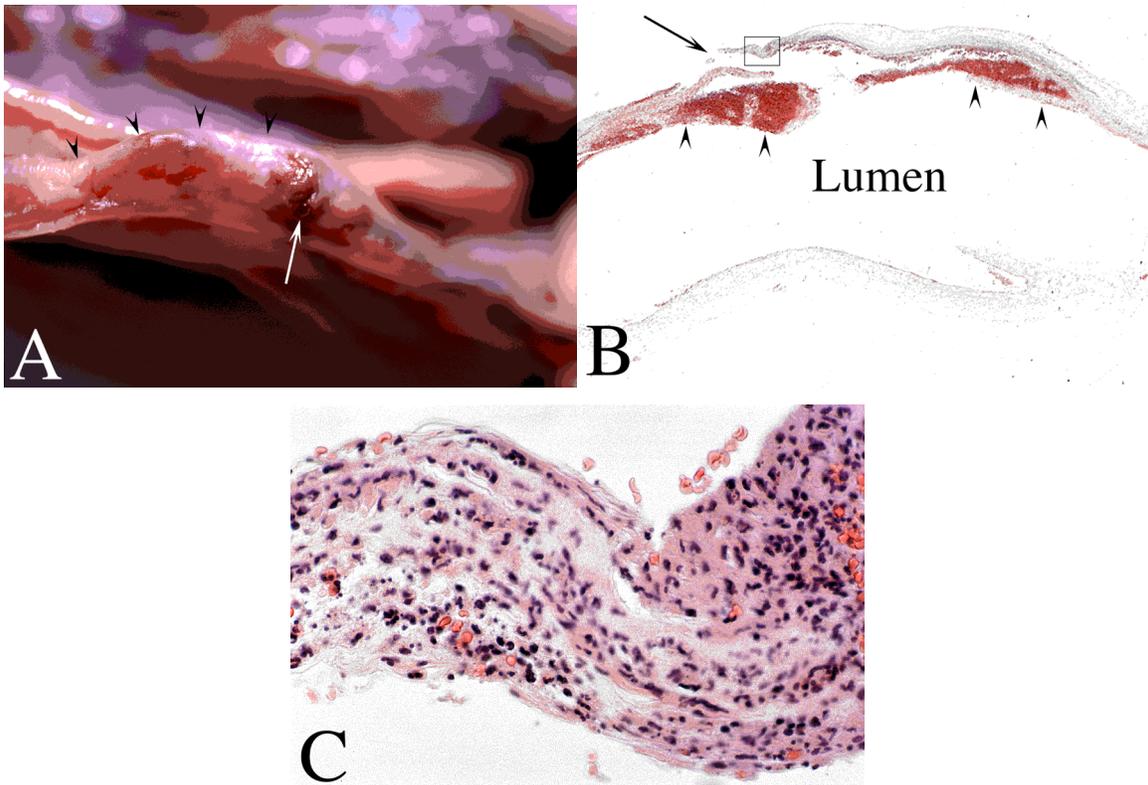

Figure 15. Rupture of a velamentous fetal vessel due to necrotizing inflammation. This term placenta had a velamentous insertion of the umbilical cord. As with the placenta shown in Figure 14, one of the fetal vessels passed over the internal cervical os. In this case an ascending infection developed several days prior to delivery which eventually eroded the vessel wall until it ruptured. A) Gross exam of the rupture site (arrow) of the vasa previa vein (arrow heads). B) Microscopic exam of a longitudinal section through the rupture site (arrow). Note fibrin clot (arrow heads) attempting to stop the hemorrhage near the site of rupture. Inset showing acute inflammatory infiltrate is demonstrated at higher magnification in C.

VII. Diagnostic utility of the umbilical cord

Increasingly, noninvasive procedures are being utilized to assess fetal well-being *in utero*. Assessment of fetal blood flow through the umbilical cord has proven to be one such measure. Utilizing ultrasound and Doppler flow measuring techniques, not only can the umbilical cord be visualized (Figure 16), but also the flow of fetal blood through these vessels can be assessed. By measuring the amount of forward blood flow through the umbilical artery during both fetal systole and diastole, an overall measure of fetal health can be obtained. In general, the more forward blood flow from the fetus to the placenta through the umbilical artery, the healthier the fetus (Figure 17).
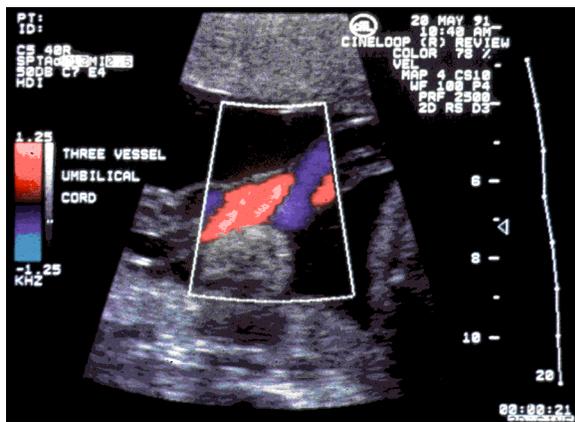

Figure 16. Doppler ultrasound of the umbilical cord. By measuring the shift in frequency of the reflected ultrasound, blood flow in the umbilical vessels can be visualized. In this example the two umbilical arteries and one vein can be easily seen within the marked off region in the center of the ultrasound image.
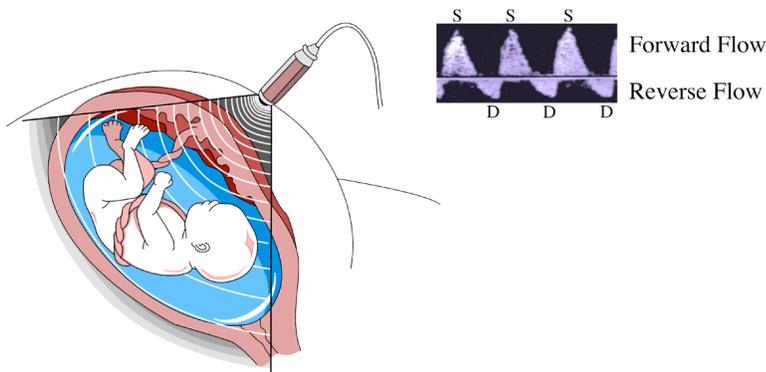

Figure 17. Doppler flow ultrasound of the umbilical cord can also be used to quantitatively assess umbilical artery blood flow. By directing the Doppler ultrasound measurement in the path of umbilical artery blood flow, a measurement of both systolic (S) and diastolic (D) flow through the umbilical artery can be made. Normally a high forward flow signal is seen during systole, followed by a lesser, but still forward flowing, diastolic pulse. In cases of severe fetal compromise, reverse flow may be seen during diastole (as shown in the inset in the upper right corner of the figure).

Certain clinical situations, however, necessitate a more invasive approach. At these times the fetus's survival may be dependent on directly evaluating or giving the fetus blood. In these cases direct puncture of the umbilical cord vessels (cordocentesis) may become necessary. This more invasive approach to fetal therapy is used only in the most serious cases since these procedures carry the risk of rupture of the umbilical vessels, which can lead to thrombosis, hemorrhage, or even vascular tamponade (Figure 18).
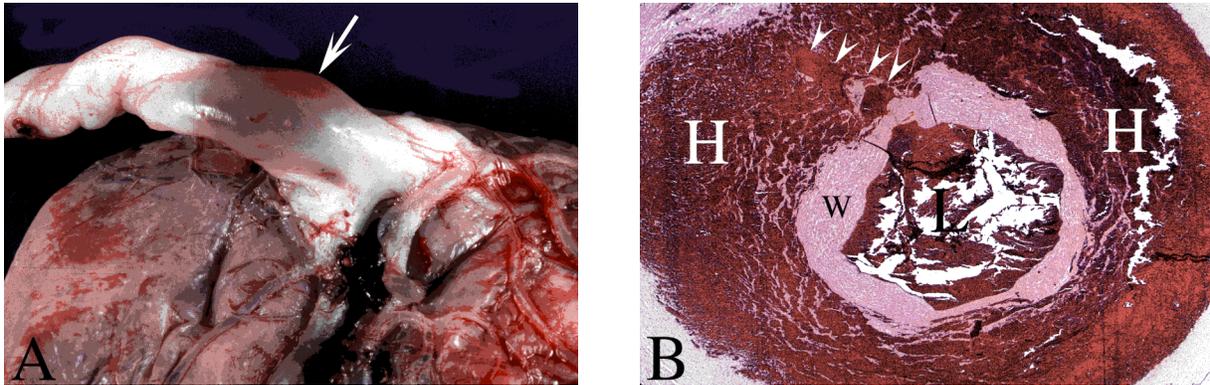

Figure 18. Therapeutic cordocentesis occasionally leads to umbilical vessel hemorrhage. A) Site of umbilical cord puncture (arrow) during an intrauterine fetal transfusion to treat severe fetal anemia. Note bulging and discoloration of cord at site of puncture. B) Cross section of umbilical cord at point of puncture which demonstrates the needle tract (arrow heads) through the artery wall (W). Rupture of the vessel resulted in perivascular hemorrhage (H) with tamponade. Artery lumen (L). The fetus experienced acute distress, was delivered by emergency Caesarean section, but unfortunately died within an hour of birth.

Further Reading

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