

The umbilical and paraumbilical veins of man

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INTRODUCTION

Although the ligamentum teres is still generally described as a fibrous remnant of the obliterated umbilical vein, a number of histological studies has shown that a small lumen persists into adult life (Baumgarten, 1891; Butler, 1954; Krahn, 1974) and also that its wall shows a distinct zoning (Butler, 1954; Krahn, 1974).

Clinical approach to the portal system via the patent umbilical vein has been undertaken in neonates for therapeutic purposes since Sidbury (1923) first undertook exchange transfusion, although catheterization of the vein is not without hazard (Larroche, 1970; Kitterman, Phibbs & Tooley, 1970). Considerable success has now been achieved in cannulating the upper part of the ligamentum teres in adults for a variety of diagnostic and therapeutic procedures (Bevan, 1973). This development followed the demonstration by Gonzales (1959) that good portal venograms are obtained in cadavers by cannulation if a probe is first passed along the apparent lumen of the 'ligament' into the left branch of the portal vein. It is of some importance, therefore, that structural details of the 'ligament' at all ages should be known.

The present investigation included macroscopic, microscopic and radiological studies on the umbilical and closely associated paraumbilical veins of man. The results will be described under these headings, and the term 'umbilical vein' will be used throughout, in preference to 'ligamentum teres'.

Although studies were made on the paraumbilical veins during the nineteenth century, and classification into groups undertaken (e.g. His, 1885), they receive scant attention in present-day textbooks and there is no official recognition of distinct groups in the *Nomina Anatomica* (1977). A brief review of the relevant earlier studies will therefore be given before presenting the results; recourse to the original eponymous nomenclature is unavoidable.

MATERIALS AND METHODS

Following study of the general anatomical features of the umbilical vein by dissection of an embalmed cadaver, a total of 54 post mortem specimens of liver and attached falciform ligament was obtained from subjects ranging in age from birth to 93 years. In some cases a variable length of the lower part of the umbilical vein had been removed or damaged, but the intact specimens included those from neonates and from children aged 1½, 4, 7 and 11 days; 3 months; 1, 1½, 4 and 6½ years. Many of the specimens served for more than one type of investigation, and 10% formol saline was employed for fixation.

Prior to gross dissection, specimens were fixed by immersion, but radiological

investigations were made on fresh specimens, and these were subsequently fixed for other investigations.

Histological study was undertaken on the upper, middle and lower thirds of the umbilical vein, the umbilical-portal junction, the paraumbilical veins, the ductus venosus and the left branch of the portal vein, but samples of all tissues were not examined from each specimen. Following embedding in paraffin wax the tissues were sectioned at 7 μm and stained with haematoxylin and eosin, Miller's elastin-van Gieson and Masson's trichrome stains.

Radiological investigation of the patency and connections of the umbilical and paraumbilical veins was undertaken by injection of the contrast medium 'Hypaque' into the paraumbilical veins, and also by retrograde injection of the umbilical vein from the portal system.

In the former approach, 1-4 ml were injected via a very fine hypodermic needle into a major paraumbilical vein, just below the liver. Retrograde injection of the umbilical vein was readily achieved in neonates by inserting a tapered glass cannula into its hepatic extremity via the left branch of the portal vein. In older specimens, however, the cannula was tied into the terminal part of the left branch of the portal vein (the *recessus umbilicalis*), and most of its divisions were ligated to prevent preferential flow to the liver, and also to maintain pressure within the lumen. When the recessus was well filled by moderate pressure, it was gently milked towards the umbilical vein.

RESULTS

Anatomical observations

The umbilical vein

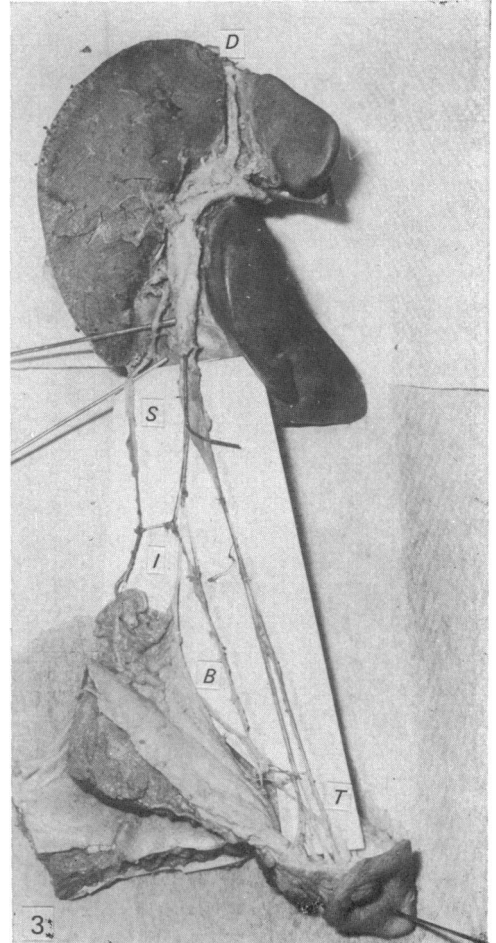
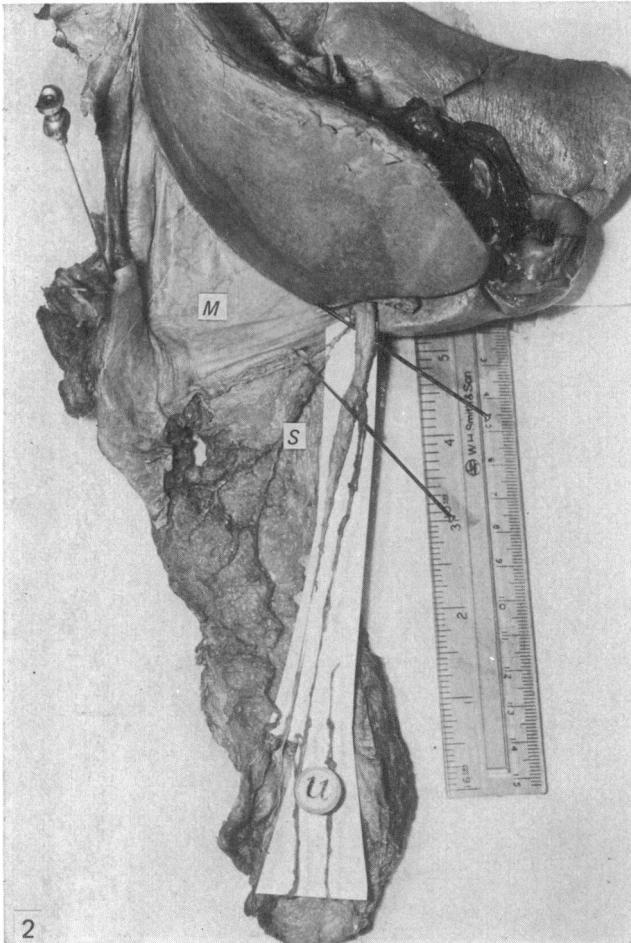
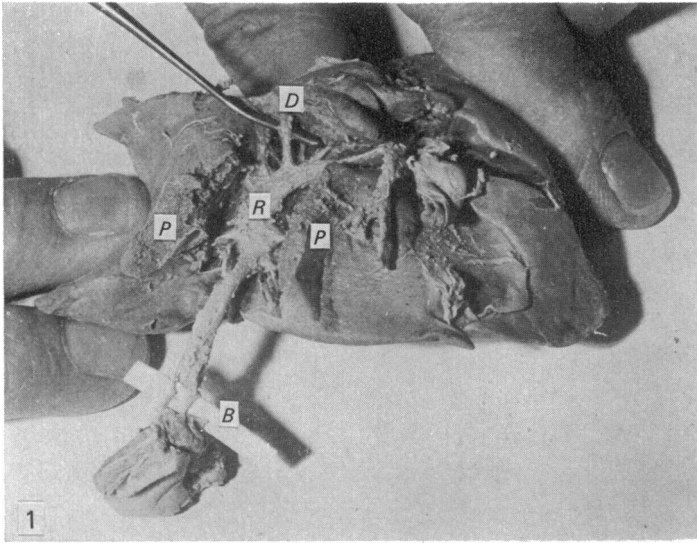
In neonates the umbilical vein shows no essential difference in gross morphology throughout its length, and it passes into direct continuity with the termination of the left branch of the portal vein. The latter forms a slight expansion, known as the *recessus umbilicalis* (Rex, 1888), from which divisions are given to the quadrate lobe as well as to the left lobe of the liver (Fig. 1). The umbilical vein is also in direct alignment with the ductus venosus, and since both are patent, a probe may be passed from the ductus into the umbilical vein as far as the umbilicus, via the recessus.

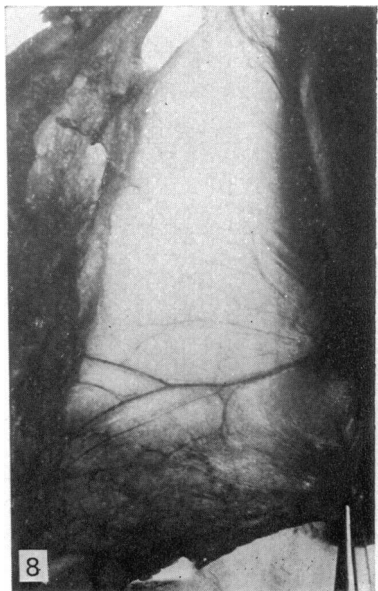
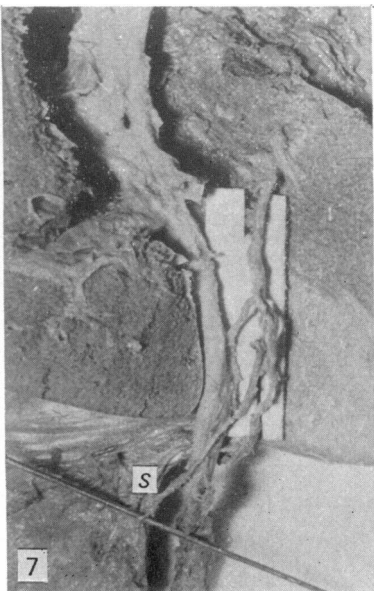
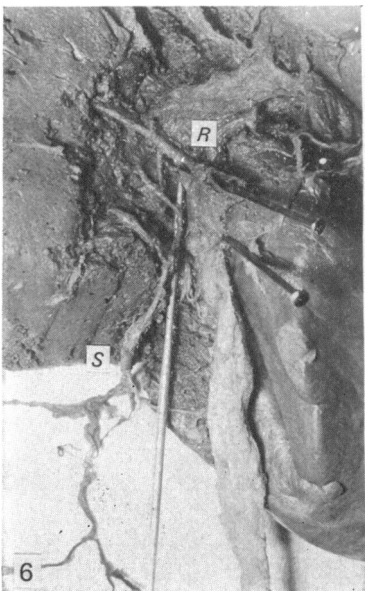
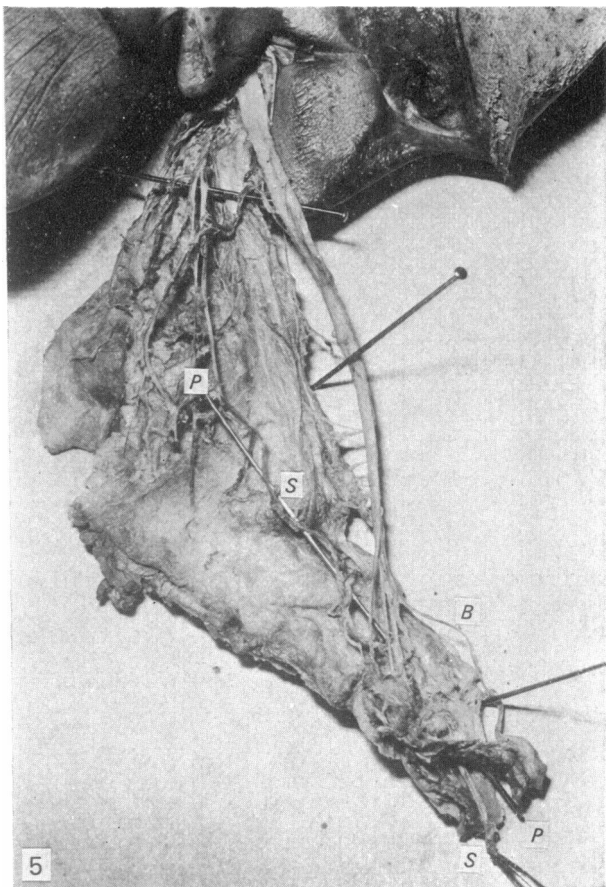
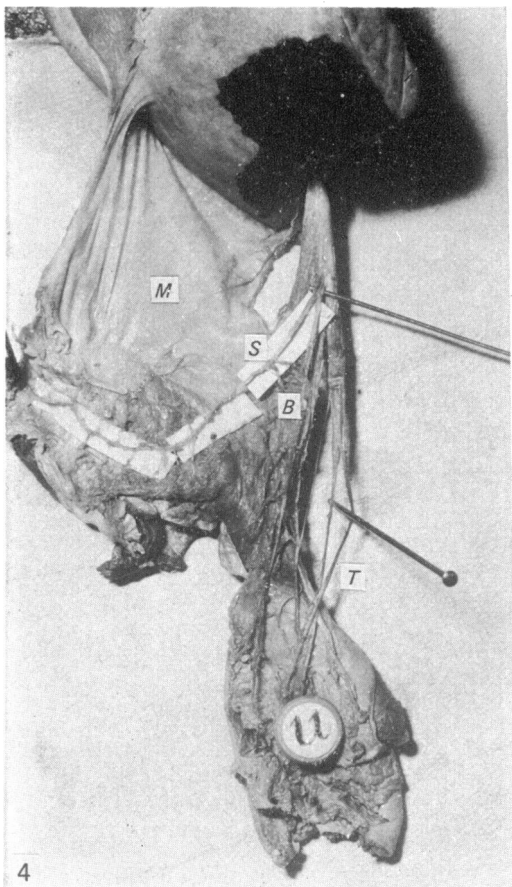
Within a few weeks the ductus is considerably reduced in diameter and shows a slight shift to the right with respect to the umbilical vein (Fig. 1), whilst in the adult the vessels are considerably out of alignment (Fig. 3). The shift to the right probably results from the greater growth of the right lobe of the liver after birth,

Fig. 1. Liver and umbilical vein; 3 weeks. Burow's paraumbilical veins (*B*) enter the umbilical vein which passes into direct continuity with the recessus umbilicalis (*R*). An overlying pons hepatis (*P-P*) has been resected. The contracted ductus venosus (*D*) is almost in alignment with the umbilical vein.

Fig. 2. Liver and falciform ligament; 84 years. Burow's veins (one broken) ascend from below the umbilicus (*U*) and enter the umbilical vein. The membranous part of the falciform ligament (*M*) contains Sappey's superior paraumbilical veins, whilst the lower, fatty part contains Sappey's inferior veins, the main channel of which (*S*) enters the hepatic fissure for the umbilical vein.

Fig. 3. Umbilical and paraumbilical veins; 18 years. More than half of this umbilical vein is divided into tails (*T*). A Burow's vein (*B*) is linked by an intercalary vein (*I*) to Sappey's main channel (*S*). The latter gives divisions to the liver, including the quadrate lobe. The ductus venosus (*D*) is now out of alignment with the umbilical vein (compare Fig. 1).





which Meyer & Lind (1966*a*) suggest is a consequence of a preferential flow of blood to that lobe.

† From gross dissection of the cadaver it was confirmed that the adult umbilical vein deviates slightly to the right of the mid-line as it ascends (Piccone & LeVeen, 1967; Hardy & Nye, 1969), and this is taken into account when making the surgical incision to expose the vein. It also deviates from the anterior abdominal wall as it follows the free margin of the falciform ligament. In the cadaver the angle was approximately 35°, which is similar to the average value of 40° obtained from previous studies (Braastad, Condon & Gyorkey, 1967; Krahn, 1974).

The adult vein may be divided into three segments which, although not of equal length, are conveniently referred to as 'thirds' (Krahn, 1974). The upper third lies within a deep fissure in the visceral surface of the liver and extends from the free margin to the recessus umbilicalis at the porta hepatis (Figs. 3, 6, 7). In 52 % of the specimens studied it was covered by a bridge of liver tissue, known as the *pons hepatis* (Fig. 1), which is comparable with the average value of 40 %, calculated from the figures given by previous investigators (Braastad *et al.* 1967; Ram & Didolkar, 1973; Krahn, 1974). It has been proposed that such bridges, which may also be associated with the ductus venosus and inferior vena cava, are remnants of the original liver tissue which covered those vessels, but which are lost, in whole or in part, following relative deceleration of liver growth (Michels, 1955).

Near the umbilical-portal junction, one or more fine branches from the left and middle divisions of the hepatic artery were found descending alongside the umbilical vein and supplying its wall.

The middle third is of similar gross morphology to the upper third, but the lower third, which sometimes composes almost half the total length of the vein, is subdivided into strands or 'tails', reminiscent of a *cauda equina*. The strands originate at the conical, lower extremity of the middle third and diverge as they approach their attachment to the posterior wall of the rectus sheath in the region of the umbilicus (Figs. 3-5). It has been claimed that they consist of fibrous tissue (Robin, 1860; Krahn, 1974), but Butler (1954) has suggested that they are developed from the fibro-elastic coat of the vein.

Fig. 4. Umbilical and paraumbilical veins; 4 years. The lower third of the umbilical vein has already divided into tails (*T*) attached at the umbilicus (*U*). The pattern of Sappey's inferior veins is unusual. A major channel (*S*) from just below the membranous part of the falciform ligament (*M*) enters the umbilical vein, together with a channel (*B*) which could be either a Burow's or a Sappey's vein.

Fig. 5. Umbilical and paraumbilical veins; 60 years. Only the lowermost part of this umbilical vein has divided into tails, so Burow's vein (*B*) opens at a low level. The main channel of Sappey's inferior veins (*S-S*) enters the right rectus sheath through a hiatus. The probe (*P-P*) follows its passage into the sheath.

Fig. 6. Sappey's inferior veins; 73 years. The umbilical vein and recessus umbilicalis (*R*) are turned aside to show the main channel (*S*) forming a plexus at the liver margin before ascending in the umbilical fissure. Divisions are given to the quadrate and left lobes, and to the recessus.

Fig. 7. Sappey's inferior veins; 54 years. An unusual case where the main channel (*S*) crosses superficial to the umbilical vein and, after forming a plexus, ascends on its right to enter the quadrate lobe.

Fig. 8. Sappey's superior veins; 65 years. Transillumination of the upper, membranous part of the falciform ligament shows the arcades formed by these veins.

The paraumbilical veins

Historical review. From a study of late fetuses, Burow (1838) described a pair of veins which ascend from the inferior epigastric veins alongside the umbilical vein and, after uniting into a single channel, drain into its upper part. The next observations of significance were made by Sappey (1883), who studied post mortem specimens from cases of advanced portal hypertension in which the veins were distended. He considered them to be insignificant structures in the normal cadaver. His conclusions on the general arrangement and connections of the veins have not been contested, apart from his claim that the adult umbilical vein has neither lumen nor tributaries; they subsequently became known as 'Sappey's veins'.

Sappey concluded that these veins, which he referred to as accessory portal veins, are divisible into a superior and an inferior group. The superior group drains the median part of the diaphragm and traverses the upper part of the falciform ligament to reach the convex surface of the liver, where they enter the sublobular divisions of the portal vein. The venules of the inferior group traverse the inferior part of the falciform ligament and enter the hepatic fissure. Inferiorly they communicate with the epigastric and cutaneous veins, and when dilated following portal hypertension, one channel becomes selectively enlarged to connect the right epigastric vein with the liver.

Later investigations showed that the umbilical vein and the veins of Burow may also become dilated in portal hypertension (Baumgarten, 1891), and the dilated Burow's veins communicate with dilated deep epigastric veins after piercing the rectus sheath (Butler, 1952). It has also been reported that Burow's veins occasionally enter the portal system directly, and then correspond to inferior veins of Sappey (Baumgarten, 1891; Joris, 1905). The reverse situation, in which some of Sappey's veins drain into the umbilical vein, was also observed by Baumgarten and confirmed by Meriel (1902), and they became known as the 'intercalary veins of Baumgarten'.

Present results. It was confirmed that this system of veins can be conveniently divided into three groups, namely the veins of Burow and the superior and inferior groups of Sappey. When undertaking their dissection, however, it was found that whereas the layers of the falciform ligament are separated by fatty connective tissue below the free margin of the liver, above that level, where the ligament passes between the diaphragm and the convex surface of the liver and contains the superior group of Sappey's veins, the fat is lost and it becomes membranous (Figs. 2, 4, 8). Owing to the adherence of the layers the veins could not be demonstrated by dissection, but since the membrane is translucent they could be visualized and photographed by transillumination. The system consists of fine channels which form a series of arcades, somewhat similar to the tributaries of the portal vein from the intestine (Fig. 8).

The inferior veins were dissected from the fatty tissue of the lower part of the falciform ligament after removing one of its layers, and Burow's veins were dissected free from the sides of the umbilical vein to which they are usually adherent superiorly. Although of small calibre, the paraumbilical veins proved far from delicate, and this point will be referred to later.

The veins of Burow terminated independently in the middle third of the umbilical vein at a variable level, and none entered the portal system directly (Figs. 1-5). In the 3 weeks specimen shown in Figure 1 they are seen entering the lower part of the umbilical vein. If the original point of entry is low, as in this case, it must later

change to a relatively higher level, following growth changes and subdivision of the lower third into strands.

Sappey's inferior veins drain into a main channel which extends from the umbilical region to the liver, and it receives some of its largest tributaries from the broad junction zone between the fatty and membranous parts of the falciform ligament (Figs. 2, 4, 5). It enters the depths of the fissure for the umbilical vein, i.e. anterior to the vein; to become the terminal channel, which is very difficult to dissect. Not only does it lie deep to the umbilical vein and recessus umbilicalis, which have to be turned aside after sectioning some divisions of the latter, but it is also bound in dense connective tissue derived from Glisson's capsule. In addition, it is accompanied by the small descending arteries which supply the wall of the umbilical vein.

The channel communicates with the portal system in a variable manner. In some cases it divides into a plexus near the free margin of the liver before continuing as a single channel (Figs. 6, 7). A direct branch to the free margin of the quadrate lobe is commonly given, whether or not a plexus is formed, and the channel terminates in branches to the liver, the recessus umbilicalis, or one of its divisions, or even ends in the quadrate lobe (Figs. 3, 6, 7).

Communications between Sappey's and Burow's veins by intercalary veins were occasionally observed (Fig. 3), and in one specimen Sappey's main channel terminated in the umbilical vein (Fig. 4).

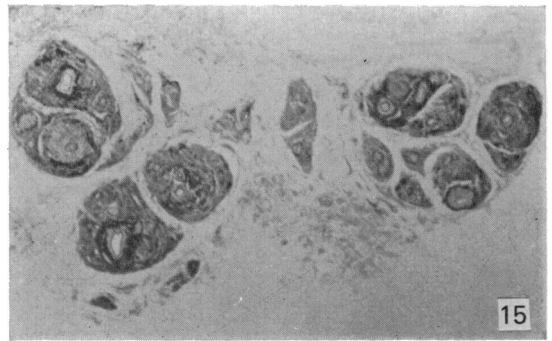
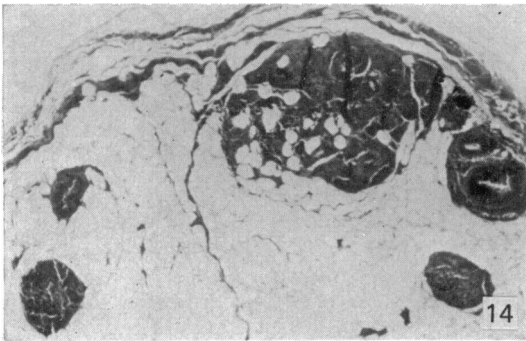
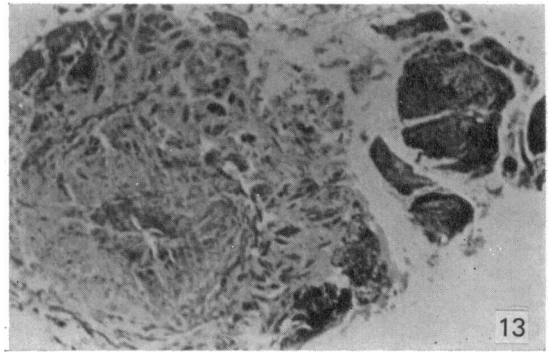
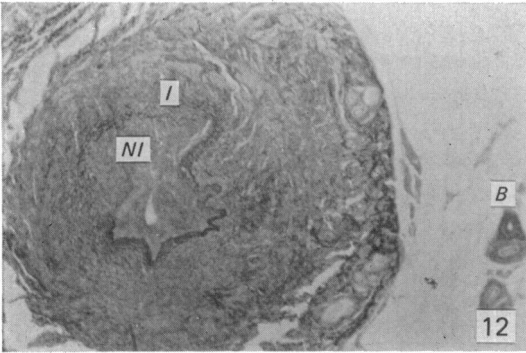
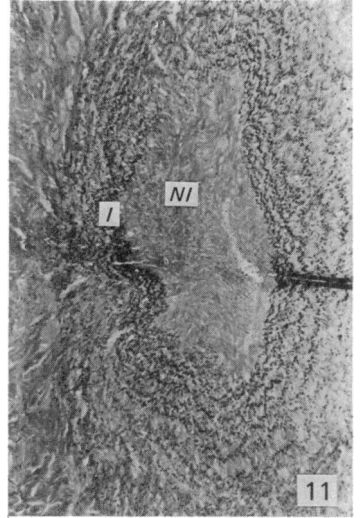
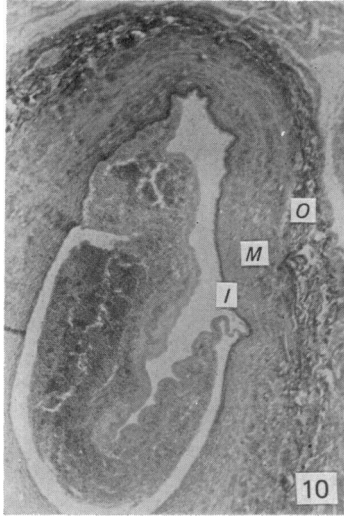
In two specimens sufficient abdominal wall was present to trace the main channel of Sappey's system below the umbilicus, and it was seen to enter the right rectus sheath through a small hiatus just above the umbilicus (Fig. 5). A Burow's vein also descended behind the sheath, but had not entered it at the level of section.

Histological observations

The umbilical vein

The walls of the umbilical vessels contract within 15–60 seconds after birth (Moinian, Meyer & Lind, 1969), and this is probably initiated by a number of factors (Dawes, 1968; Hiller & Karim, 1968). It was previously demonstrated by Chacko & Reynolds (1954) that the vessels within the umbilical cord shorten after the contraction, and their external diameters are reduced by approximately two thirds. The arterial walls then show a sevenfold thickening, and the vein wall a tenfold. These changes depend upon the arrangement of the smooth muscle in crossing helicoidal spirals. Their contraction, assisted by the well-developed elastic laminae, causes bunching of the loose inner zone tissue, and this occludes the lumina of the arteries, although the lumen of the vein remains patent and contains blood. The contracted, very thick muscular wall of the vein lies adjacent to an internal elastic lamina, and most of its fibres show a roughly circular direction, following a change in the pitch of their spirals (Fig. 9).

The intra-abdominal segment shows considerable differences in structure and contains little smooth muscle (Barclay, Franklin & Prichard, 1944; Butler, 1954). At birth the wall has not fully contracted, so the lumen is widely patent and blood-filled (Fig. 10). Within a week, however, considerable contraction has occurred, the wall thickens markedly and the lumen becomes compressed into a long narrow oval, or sometimes into a stellate shape in its upper part. The components of the wall run essentially in a longitudinal direction and show a distinct arrangement in three zones (Fig. 10). Longitudinal sections through the umbilical scar showed that as the



vein traverses the region the muscular component is substantially reduced, whilst the elastic lamina divides into longitudinal fibres which enter the three zones.

The inner zone is narrow and lies immediately adjacent to the lining endothelium. It is essentially musculo-elastic, and numerous fine elastic fibres lie between closely packed smooth muscle cells. The middle and outer zones are of approximately the same width at this stage and are essentially fibro-elastic. In the middle zone the collagen is loosely arranged and the elastic fibres are fine and sparse, whereas in the outer zone the collagen is aggregated in coarse bundles between which are numerous coarse elastic fibres. A small amount of longitudinally arranged smooth muscle is present at the periphery of the outer zone, and a few wisps of more circularly arranged fibres lie at the periphery of the middle zone. The latter fibres are not seen in the adult, as was also noted by Butler (1954). In tangential sections the outer fibres are seen to be arranged in crossing spirals.

The vein wall is rich in blood vessels, and arteries are present in the outer zone (Fig. 12). Numerous thin-walled veins traverse the wall, and it was noted in longitudinal sections that they pursue an ascending course before entering the lumen. In the surrounding tissue of the falciform ligament, which forms an adventitial coat, there are many somatic vessels as well as paraumbilical veins, lymphatic vessels and occasional nodes.

Postnatal changes in the vein include obliteration of the greater part of the lumen, subdivision of the lower part into strands, and changes in the tissue components of the intact upper part.

The greater part of the lumen is obliterated by a subendothelial proliferation of loose connective tissue, the early stages of which may be found at the time of birth (Butler, 1954). The structural pattern which results is shown in Figure 12, which is from a 1½ year specimen, but it was already present at 6 weeks and no significant change was observed until late adult life.

Fig. 9. T. S. extra-abdominal umbilical vein; 3 days. The contracted oval lumen contains blood and is surrounded by a single elastic lamina, whilst the remainder of the wall consists of a thick coat of spirally arranged smooth muscle. Van Gieson-elasticin. $\times 32$.

Fig. 10. T.S. intra-abdominal umbilical vein; newborn. The large oval lumen contains blood. The wall, which is not yet fully contracted, shows a narrow, inner musculo-elastic zone (*I*), a middle zone (*M*) of loose fibro-elastic tissue, and an outer, dense fibro-elastic zone (*O*). Van Gieson-elasticin. $\times 32$.

Fig. 11. T.S. umbilical vein; 3 months. High power picture to show the new inner zone (*NI*) created by a proliferation of loose subendothelial connective tissue, and the eccentrically placed residual lumen which contains blood. The original inner zone (*I*) roughly indicates the outline of the original (contracted) lumen. Van Gieson-elasticin. $\times 80$.

Fig. 12. T.S. umbilical vein; 1½ years. Low power view to show the eccentric residual lumen within the asymmetrical proliferation which forms the new inner zone (*NI*). Opposite to the lumen the musculo-elastic ring shows some dispersion (*I*). A Burrow's vein (*B*) lies at the periphery.

Fig. 13. T.S. umbilical vein; 38 years. Section just above the tails shows break-up of the vein wall; and the portions undergoing separation, as well as the inner musculo-elastic zone, show a great increase in elastic tissue. Van Gieson-elasticin. $\times 32$.

Fig. 14. T.S. umbilical vein; 56 years. Section near origin of the tails shows some tails already separated, and the remainder of the vein is undergoing break-up, with fatty infiltration. Masson trichrome. $\times 32$.

Fig. 15. T.S. tails of umbilical vein; 6½ years. These vascular fibro-elastic strands are of variable morphology. They have a high content of elastic tissue and an occasional content of smooth muscle. Van Gieson-elasticin. $\times 32$.

The proliferation forms a new inner zone, at the periphery of which lies the musculo-elastic ring which formed the original inner zone, and now roughly indicates the size of the original lumen after its contraction. In most sections the residual lumen is eccentrically placed and there is little proliferation in its vicinity, whereas it is considerable within the remainder of the ring, and usually displaces and disperses its tissues on the side opposite to the lumen. This suggests that the flattened oval lumen is obliterated by compression along both sides of its long axis, except at the extremity where proliferation is minimal. Occasionally a narrow space extends from the residual lumen, which probably indicates the final stage of compression (Figs. 11, 12).

If the lumen initially assumes a stellate form, reduction is probably effected by compression of the narrow rays of the star. The residual lumen is, in fact, sometimes less eccentrically placed in the upper than in the lower part of the vein.

Beyond 11 days the youngest specimen in which the lower part of the vein was examined was aged 6½ years, and the characteristic strands had already developed. They vary in size and outline and show the same structure as those of adults of all ages (Fig. 15). Their components lack orderly arrangement but are longitudinal in direction. Most strands contain vascular channels, including arteries, and some contain a little smooth muscle, but they are essentially fibro-elastic structures and the elastic content is high.

Examination of sections from the site of origin of the strands established that they originate from progressive fragmentation of the vein wall, and the process is accompanied by fatty infiltration of the areas of breakdown. In the segments undergoing separation the elastic fibre content is markedly increased (Fig. 13), and this is reflected in the high content within the resulting strands. Where the greater part of the wall has broken down the strands are widely separated and the intervals are occupied by fatty tissue (Fig. 14). Derivation of the strands from different parts of the vein wall therefore accounts for their variable composition and vascular content.

The umbilical-portal junction is patent, even in elderly subjects. Although the opening into the recessus is funnel-shaped in the early postnatal period, the asymmetrical proliferation within the vein raises a spur at one side of the opening from which the wall of the recessus diverges sharply away (Fig. 16). The zoned structure of the umbilical vein is continued into the wall of the recessus, which is thicker on the side of the spur and also into the left branch of the portal vein. Within the loose connective tissue of the spur there is an interlacement of smooth muscle and fine elastic fibres, and near its base a short narrow band of circularly arranged smooth muscle lies subjacent to the endothelium. This is suggestive of a sphincteric arrangement.

With advancing age, degenerative changes take place in the upper part of the vein. Although the average diameter of the residual lumen remains remarkably constant at approximately 0.2 mm, it is gradually obliterated from below upwards. However, a variable length of the uppermost part remains patent, and contains blood, even in old age. Following reduction of the muscular and elastic components of the vein wall it becomes more fibrous in structure. The inner zone becomes denser and more contracted, and loss of tissue from the surrounding musculo-elastic ring may reduce it to a small crescent. Finally, some break-up of the outer part of the vein wall occurs, accompanied by fatty infiltration, and consequent loss of contour (Fig. 17).

The ductus venosus

In neonates this channel consists of only two zones, and both consist of longitudinally arranged fibro-elastic tissue. In the inner zone the collagen is loosely arranged and the elastic fibres are fine and sparse, whilst in the broader outer zone the collagen is aggregated into coarse bundles between which are numerous coarse elastic fibres (Fig. 18). Many small thin-walled veins are present throughout the wall, and the surrounding connective tissue is rich in blood and lymphatic vessels, lymph nodes, nerve bundles and ganglia, and in one young specimen a mass of chromaffin tissue was present.

The process of obliteration of the collapsed lumen is similar to that described for the umbilical vein, but is later in onset. An asymmetrical proliferation of the inner zone compresses the greater part leaving a small eccentrically placed channel within the region of minimal proliferation. In the region of maximal proliferation the outer zone is displaced and its tissues somewhat dispersed (Fig. 19).

The residual lumen, which contains blood, is gradually obliterated from the portal extremity, so that in later life a variable length is confined to the caval extremity. In addition, the inner zone becomes more contracted, whilst a small quantity of longitudinally arranged smooth muscle fibres appear as scattered groups in the inner zone and as small, irregularly distributed groups in the outer zone, chiefly at the periphery.

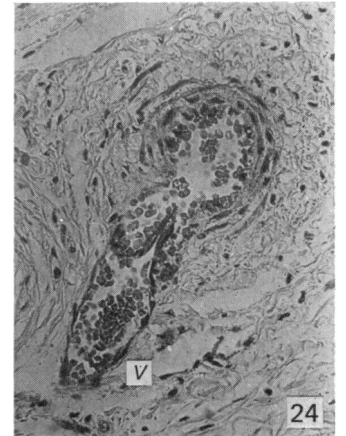
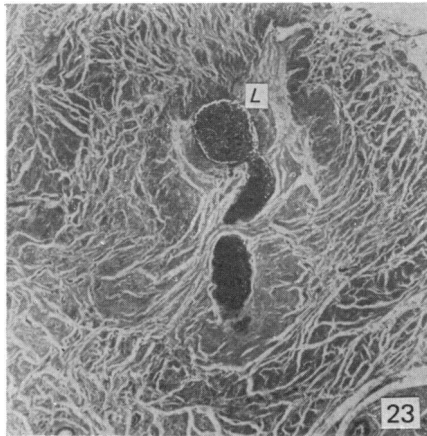
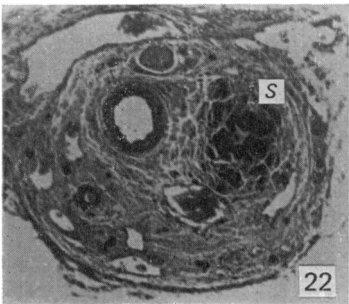
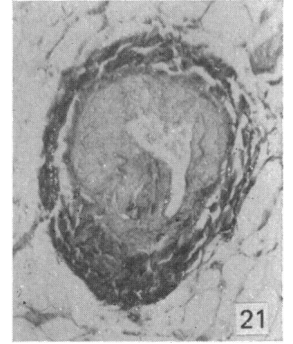
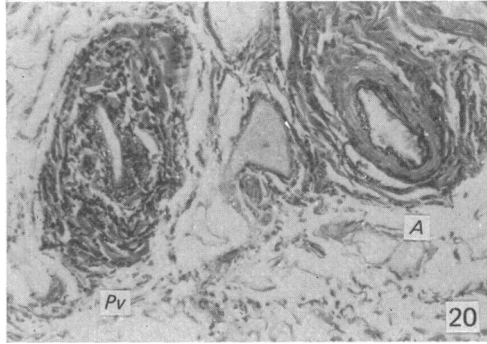
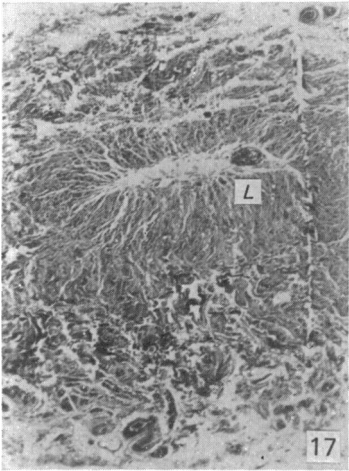
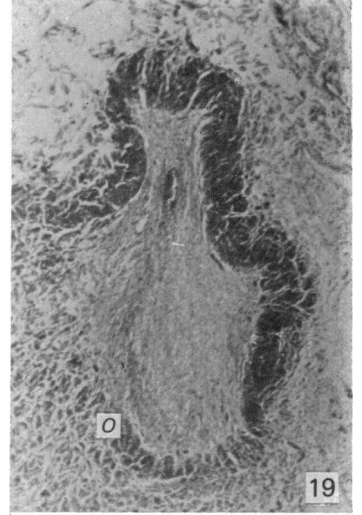
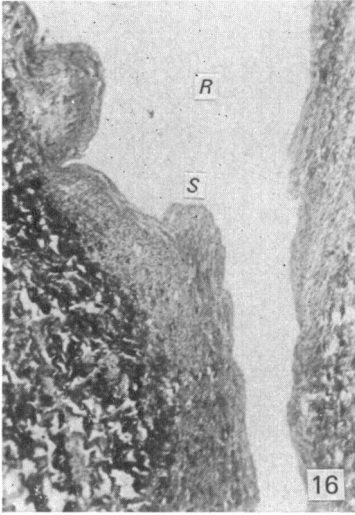
The paraumbilical veins

These vessels proved readily identifiable in sections since they have thick walls and are basically similar in structure to the umbilical vein, although their lumina are not reduced by tissue proliferation. They show a superficial resemblance to the accompanying arteries, but they are larger, have even thicker walls, and their components, which are arranged in two zones, have an essentially longitudinal direction (Fig. 20). This structural sturdiness is clearly the reason that they withstand detailed dissection. Burow's veins lie close to the umbilical vein (Fig. 12) and may occupy a groove in its wall and, in keeping with the macroscopic observations, they are not seen in sections of its uppermost part.

The inner zone is musculo-elastic. The elastic fibres are fine and a few circularly arranged smooth muscle fibres lie at the inner aspect of the zone. The outer zone is fibro-elastic and wider. The elastic fibres are coarse and lie between bundles of collagen, whilst a few longitudinal bundles of smooth muscle are distributed irregularly at the periphery (Fig. 20). The probable termination of a Burow's vein was observed in one umbilical vein specimen. This large, blood-filled vessel was traced from the middle zone to its point of entry into the lumen. Beyond the middle zone, residual parts of its supporting coats were lost (Fig. 23).

The terminal channel of Sappey's inferior veins is particularly thick-walled, and within the hepatic fissure it is associated with a neurovascular complex embedded in a dense fibrous bundle derived from Glisson's capsule, with a few elastic fibres at the periphery (Fig. 22). These relationships are clearly the reason for the difficulty encountered in dissecting the channel.

The veins of the superior group are particularly thick-walled and they can be identified with the naked eye in stained transverse sections of the membranous part of the falciform ligament. They lie at fairly regular intervals in the narrow space between the two layers, which is in keeping with the macroscopic observations, and between them are small arteries and thin-walled veins. They differ from the other



paraumbilical veins in that the inner musculo-elastic zone is thicker than the outer fibro-elastic zone, and a proportion of its elastic fibres may form a partial internal lamina (Fig. 21).

There was evidence that communication between the systemic and paraumbilical veins is of two types, namely by direct continuity and by entry as tributaries. Within both the fatty and membranous parts of the falciform ligament large veins of transitional structure were occasionally seen, suggesting structural continuity. Part of the vein wall showed the thick, zoned structure of a paraumbilical vein, whereas the remainder was considerably thinned, chiefly from loss of tissue from the outer zone, and this region was partially collapsed. In two instances a thin-walled systemic vein was seen entering a paraumbilical vein as a tributary, and the site of entry was guarded by a valve (Fig. 24).

Radiological observations

In neonates the wide lumen of the umbilical vein is readily filled by retrograde injection of contrast medium as far as the umbilicus (Fig. 25), but an 11 days specimen showed considerable narrowing of the lower third. In an intact specimen of 6½ years there was only a tiny residual lumen confined to the upper half of the vein. Although it eventually becomes confined to the upper third of the vein following obliteration from below, the diameter of the lumen remains unchanged, even in old age (Fig. 26).

In three specimens the medium entered Sappey's inferior veins instead of the umbilical vein, and the probable reason is that some divisions of the recessus umbilicalis, with which they communicate, were not among those ligated prior to the injection. The radiographs confirmed that their terminal channel has a variable mode of communication with the portal system. In one case it ascended to the recessus umbilicalis, in another it gave a division to the quadrate lobe of the liver prior to ascending, whilst in the third it formed a close plexus below the liver margin before communicating directly with the portal system within the quadrate lobe (Fig. 27 and compare with Fig. 6).

Fig. 16. L.S. umbilical-portal junction; 1 year. The junction is patent. Spur formation (*S*) is complete and the wall of the recessus (*R*) diverges away from the spur. Van Gieson-elastin. $\times 32$.

Fig. 17. T.S. umbilical vein; 84 years. In old age the lumen (*L*) is still patent in the upper part of the vein and contains blood, but the wall is more fibrous in character and there is partial breakdown of the outer zone, with fatty infiltration. Masson trichrome. $\times 32$.

Fig. 18. T.S. ductus venosus; 3 months. The inner zone (*I*) shows early proliferation. The outer, fibro-elastic zone is denser. Masson trichrome. $\times 20$.

Fig. 19. T.S. ductus venosus; 2½ years. The proliferation is asymmetrical and the residual lumen, which contains blood, is eccentric. In the region of maximal proliferation the tissues of the outer zone (*O*) are dispersed (compare Fig. 12). Masson trichrome. $\times 32$.

Fig. 20. A paraumbilical vein (*Pv*) has a very thick wall with an inner musculo-elastic and an outer fibro-elastic zone. The accompanying artery (*A*) has a different structure. Van Gieson-elastin. $\times 80$.

Fig. 21. A paraumbilical vein of Sappey's superior group is very thick-walled, and the elastic fibres of the thick, inner musculo-elastic zone form a partial lamina. Van Gieson-elastin. $\times 80$.

Fig. 22. The thick-walled terminal channel of Sappey's inferior veins (*S*) is contained within a neurovascular bundle at the liver surface. Van Gieson-elastin. $\times 32$.

Fig. 23. T.S. umbilical vein; 2½ years. A large vessel opening into the residual lumen (*L*) is probably a Burow's vein. H & E. $\times 32$.

Fig. 24. A thin-walled systemic vein (*V*) within the falciform ligament opens into a small paraumbilical vein, and the entry is guarded by a valve. H & E. $\times 200$.

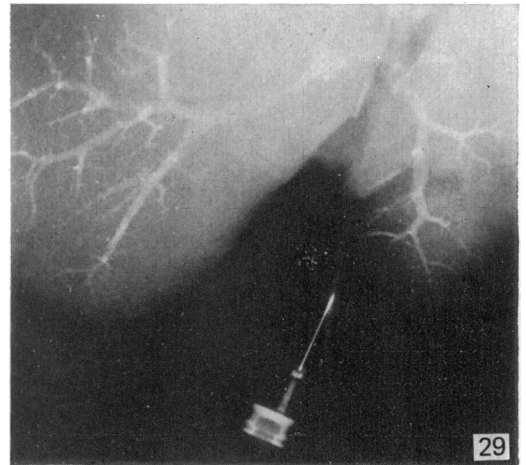
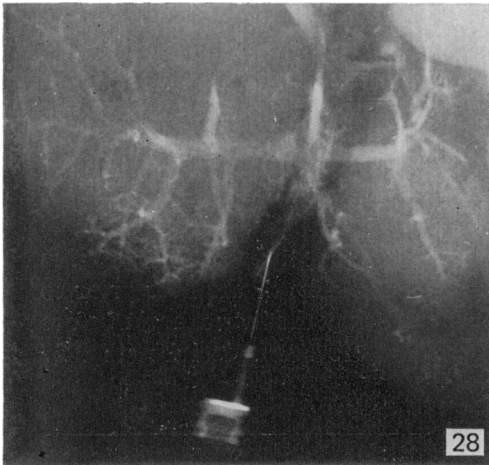
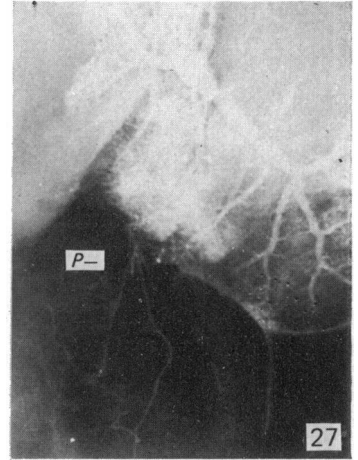


Fig. 25. Umbilical vein; 1½ days. The wide lumen is filled as far as the umbilicus by retrograde injection. All radiographs were taken following injection of the contrast medium 'Hypaque'.

Fig. 26. Umbilical vein; 77 years. Retrograde injection shows a small residual lumen in only the upper third of the vein, but its diameter is similar to that in the child.

Fig. 27. Sappey's inferior veins; 93 years. Retrograde filling shows a plexus (P) formed by the terminal channel at the liver margin which communicates with the quadrate lobe (See Fig. 6).

Fig. 28. Sappey's inferior veins; 67 years. Direct injection of the main channel shows that in this case it communicates with the portal system after ascending in the umbilical fissure (see Fig. 3).

Fig. 29. Sappey's inferior veins; 70 years. Direct injection of the main channel in this case shows that it communicates directly with the portal system within the quadrate lobe (see Figs. 6 & 7).

Direct injection of the main channel of Sappey's inferior veins just below the liver in three specimens again confirmed that although the terminal channel communicates with the extra-hepatic part of the portal system at, or near, the recessus umbilicalis (Fig. 28), it not infrequently communicates directly with the intra-hepatic part by a branch to the free margin of the quadrate lobe (Fig. 29 and compare with Figs. 6 and 7).

DISCUSSION

As in the case of the extra-abdominal segment, postnatal contraction of the intra-abdominal segment of the umbilical vein results in marked thickening of the wall, together with flattening, but not obliteration, of the lumen. It was confirmed that the wall of the intra-abdominal segment differs in structure from that of the extra-abdominal, and its tissues are arranged longitudinally in fibro-muscular and fibro-elastic zones. The tissue rearrangement occurs during transit through the umbilical region.

The observation of Butler (1954) that obliteration of the greater part of the lumen is effected during early childhood by a subendothelial proliferation of connective tissue was confirmed, and this tissue forms a new inner zone. The present study suggests that where the contracted lumen is of flat oval form, compression along its length leaves one extremity as the residual lumen; but if it is initially stellate, the residual lumen is the portion which remains after compression of the rays of the star.

The upper part of the residual lumen persists in adult life and conducts blood to the portal system via numerous small systemic veins which traverse its wall, and also via the paraumbilical veins of Burow. The latter enter at a variable level and it is likely that the obliterative process is arrested below that level. This is contrary to the view of Wertheimer (1886), generally accepted by pathologists (Edwards, 1951), that the presence of a lumen depends upon the recanalization of a thrombus. Furthermore, claims that its site of junction with the portal system may be obliterated or closed by membranes (Hardy & Nye, 1969; Ram & Didolkar, 1973), or collagenous tissue (Braastad *et al.* 1967), were not substantiated.

The strands which arise from breakdown of the lower third of the vein wall are essentially vascular, fibro-elastic structures. Their high content of elastic tissue, which is acquired at the time of breakdown, is retained into later life, whereas the content becomes reduced in the intact segment. This is possibly a protective development whereby the strands adjust to traction stress during bodily movement. The small veins within the strands presumably open into the residual lumen of the umbilical vein, and in all likelihood communicate with the veins of the abdominal wall at the umbilicus. The small arteries are undoubtedly part of the anastomosis between the hepatic and inferior epigastric arteries described by Kiernan (1833), and which is nutrient to the vein wall.

From a more limited study of the ductus venosus the observations of Meyer & Lind (1966*b*) that its wall at birth consists of two longitudinally arranged fibro-elastic zones, but that longitudinal bundles of smooth muscle appear in the outer zone of adults, were confirmed. However, their conclusion from the study of longitudinal sections that the lumen is soon completely obliterated was not confirmed. On the contrary, the obliterative process has a close resemblance to that of the umbilical vein, and a small eccentric residual lumen, which receives vessels traversing its wall, may be found at the caval extremity, even in elderly subjects.

The paraumbilical veins, together with the umbilical vein, form an accessory portal system which is in communication with the systemic venous system. All parts of this system lie between the layers of the falciform ligament in an ascending series, each communicating with the veins of the ventral abdominal wall at successively higher levels, and opening into the portal system in the same sequence.

It is of interest that the main channel of Sappey's inferior veins communicates with vessels within the sheath of the right rectus abdominus muscle and commonly

establishes communication with the portal system within the right lobe of the liver. It is therefore possible that this channel is the remnant of the *right* umbilical vein, and since it has been claimed that at an early stage of development the umbilical vein is the main drainage channel for the ventral body wall (Smith, 1909), the accessory portal system may be the residue of the original drainage system.

From post mortem studies it has long been known that both Burow's and Sappey's inferior veins may become dilated in cases of portal hypertension, and it is now the experience of surgeons that dilated veins within the falciform ligament in such cases may prove a hindrance during approach to the umbilical vein for the purpose of cannulation (Bevan, 1975). The additional involvement of cutaneous veins in the region of the umbilicus, resulting in the classical 'Caput Medusae', is not very common and may depend upon the development of sufficient back pressure in veins traversing the umbilical scar.

A final consideration concerns the significance of the structure of the adult umbilical vein in relation to the clinical procedures of probing and cannulation. It is quite clear that the residual lumen, which has a diameter of approximately 0.2 mm, is far too small to be the actual channel which is directly probed and cannulated, although this is commonly assumed (Braastad *et al.* 1967; Piccone & LeVeen, 1967). Furthermore, the obstruction encountered at the umbilical-portal junction, which needs to be overcome by probe passage, is not due to occlusion of the site but to the encounter of the probe with the diverging wall of the recessus umbilicalis. The results of a study of the vein and its junction site following the passage of probes and cannulae will be presented in a later communication.

SUMMARY

During its transit through the umbilicus structural changes occur in the thick wall of the extra-abdominal segment of the umbilical vein whereby the components of the intra-abdominal segment acquire an essentially longitudinal direction and become arranged in fibro-elastic and fibro-muscular zones.

The vein lumen becomes largely obliterated by asymmetrical proliferation of loose subendothelial connective tissue. The latter forms a new inner zone within which a small segment of the lumen persists in an eccentric position. This residual lumen transmits blood to the portal system from paraumbilical and systemic sources, and is retained in the upper part of the vein, even in old age. A similar process of lumen closure is observed in the ductus venosus.

In early childhood the lower third of the vein undergoes breakdown, with fatty infiltration, resulting in its complete division into vascular fibro-elastic strands, and in old age some breakdown occurs in the outermost part of the wall of the upper two thirds.

The paraumbilical veins are thick-walled and of similar structure to the umbilical vein. Together they constitute an accessory portal system which is confined between the layers of the falciform ligament and is in communication with the veins of the ventral abdominal wall. The constituents form an ascending series, namely, Burow's veins, the umbilical vein, and Sappey's inferior and superior veins. The main channel of Sappey's inferior veins may be the remnant of the right umbilical vein since it communicates with the right rectus sheath and often communicates directly with the portal system within the right lobe of the liver.

The results are of significance in relation to clinical usage of the umbilical vein.

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