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Microscopic anatomy of the vasculature of the human intestinal villus - a study with review

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SUMMARY

Until recently, works on the microscopic anatomy of the human intestinal villus had been hampered by lack of *in vivo* observations, and were based on early corrosion cast techniques before the advent of scanning electron microscopy to correctly identify the nature of the vessels seen. On review, a large number of human anatomy and histology texts carry a possibly erroneous message, as is the same with the earlier works, that there are arterioles and venules in the core of these villi. Based on recently available high resolution *in vivo* observations by endoscopy, our work by transmission electron microscopy and light microscopy techniques on cross sections of the villi shows only capillary type channels, and such is also true of those anatomy and histology textbooks that have photomicrographs of cross sections of the villi (despite their possible errors). An analytical discussion in further support of our findings is made, based on established anatomical and physiological principles.

Key words: Human intestinal villus – Microscopic anatomy – Transmission electron microscopy – Light microscopy – Vascular network/pattern – Microcirculation – Physiology of villous functions

INTRODUCTION

Older and more recent literature has amply described, mostly with illustrations, the vascular network architecture of human and animal intestinal villi. From a morphological point of view, there are two major kinds of villi in the small intestine: one is long, finger-like, and the other broad, leaf-like. For the long, slender villi, three main vascular patterns had been described and summarized by Jacobson and Noer (1952). The most often referred to had been given the term “fountain pattern” by Mall (1887), Boehm and Davidoff (1900), and Spanner (1932), in modified form, whereby there is a central arteriole going to the tip of the villus, then capillary branches fan out and go downwards to reach the rest of the villus and surface epithelial cells, with a central venule accompanying the arteriole. The body or core of the villus is traversed by a capillary network. Others described a peripheral arteriole, running under the epithelial surface, from bottom to tip, with branching capillary network in between, and a venule draining the tip to bottom, on another side of the villus. This had been referred to as the “step ladder” pattern by Henle (1873), Frey (1876), and by Testut (1923). These authors reported this pattern to occur in man and rabbits. A third, “tuft” pattern, had also been described by Stohr (1901), Szymonowicz (1902), Rauber (1909), and by Schafer (1912), showing a tuft of capillaries, arising from an arteriole at the bottom of the villus, and the capillaries collecting towards a venule at the tip, draining in a central axial position.

Most of the quoted observations were not live observations; the most common method of study being by injection of cast material, with subsequent digestion of the tissue, and study of the cast by naked eye-viewing or with the dissecting microscope, and recorded by photography. The literature abounds in illustrations of the fountain pattern

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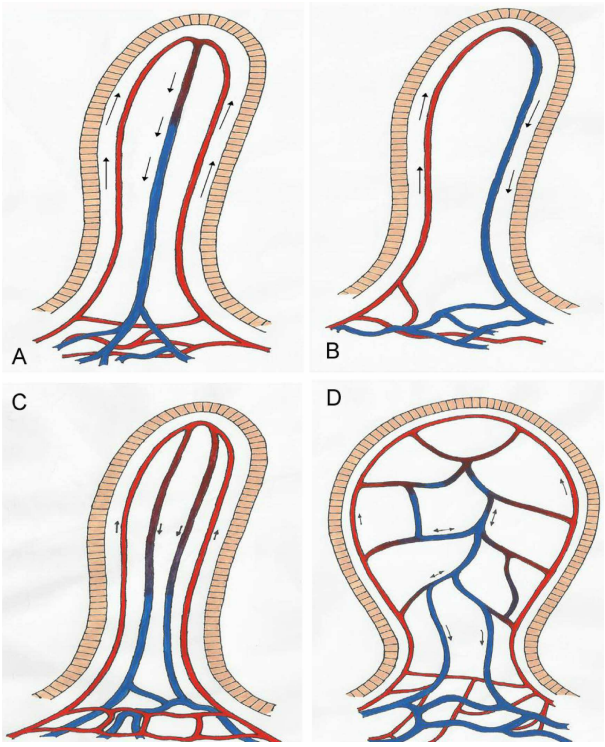

Fig. 1. (modified from Leung, 2013). **(A)** By blood flow direction, this is a reverse-fountain or funnel-drain pattern, which constitute about 40% of all villi. Arrows show the direction of blood flow, but the coloring of the vessels is not conventional, i.e. the red only indicates an arterial source, so is the blue which is the venous drainage direction. The nature of the vessels – whether arteriole, venule or capillary is the main subject of consideration in this article. **(B)** By blood flow direction, we call this the loop pattern, has about 30 percent presence in the villi, and it is somewhat like the ladder pattern described, except we can only see a few crossing vessels or the "steps" in a few villi. **(C)** By blood flow direction, this is like a mixed loop and reverse- fountain pattern, and makes up to about 20% of the villi. **(D)** By blood flow direction, this is a complex pattern, found in the leaf-like villi, that are seen around the Peyer's patches, and constitutes about 10% of all villous vascular patterns.

in animals. Corrosion cast results depend on injection pressure, experience, and material used. Incorrect injection pressure and the injection material could cause destruction and dilatation of vessels, and when the vessels are dilated, an impression of arterioles or venules is imparted (Caro et al., 2012; Giuvarasteanu, 2007). Such technical defects were noted by many authors (Hossler and Douglas, 2001; Minnich and Lametschwandtner, 2010) and are found even to the present day. Thus, the diagnosis of the nature of the vessels was presumptive at best, as admitted by Jacobson and Noer (1952). These early scientists had no scanning electron microscopy for definitive determination of the nature (arterial or venous) of the vessels by noting the impression of the endothelial cells and nuclei on the vascular cast (Aharinejad and Lametschwandtner, 1992; Ohtani and Ohtani, 2000). And not until the time of Tanigushi, et al. (1952) and Murakami (1971), who improved much on the observations and casting technique, a more certain diagnosis can be made of the nature (arterial or venous) of the vessels studied. Given these imperfections, however, the pattern of the villus architecture could have been quite reliably recorded (Guivarasteanu, 2007) except for the directions of flow in the vessels – casting solidified the flow, unlike *in vivo* studies.

There is no consensus as to the pattern in human material. There is no consensus as to the different patterns in human material, due to the scarcity of reports. Jacobson and Noer described the fountain pattern in 1952. However, one article found, by simple histological sectioning and light microscopy, that the mouse villus showed only capillaries and no arterioles or venules (Abbas et al., 1989). Recent development of endoscopy and the use of high-power direct observations, enhanced by software processor for multiband imaging, have enabled us to see in the human tissue *in vivo* what appears to be mostly a funnel-drain or reverse fountain pattern in the finger-like villi (Fig. 1A). Then, we have a loop pattern, like the ladder pattern described, but there are few intermediate crossing drainage vessels (or the "steps") to be seen (Fig. 1B); then, we have a pattern like a combined or mixed reverse fountain and loop patterns (Fig. 1C), and lastly, a complex pattern of vessels (Fig. 1D), in the leaf-like villi, which are found in those villi around the Peyer's patches.

These villus patterns are not specific in their topographical distribution in the small intestine, except the complex pattern in the leaf-like villi, which is found around the Peyer's patches. Endoscopically, we frequently observed the red cells flowing from the bottom of the villus to the tip, always in a single file. As the vessel diameter is not wider than those of the rest of the villi, we wonder if these vessels could all be capillaries rather than an arteriole and a venule. There is a periodicity of this flow, but not at a regular rate, being not comparable to the heart beat of the patient under observation, at a lower rate and also at irregular intervals or intermittently – the flow could stop for seconds, and resume again (Leung, 2013a). This is like what is described as capillary vasomotion (Tortora and Derrickson, 2012). Thus, the endoscopic observations suggest the idea that the incoming supplying vessels are not arterioles and may be post-arteriolar capillaries after a sphincter, or a pre-capillary structure such as a metarteriole, following a pre-capillary sphincter (Weiss, 1988), as it is known that the pre-capillary sphincter can control the flow by contractions and relaxations for periods of 2 to 8 seconds. In most books, the smallest arteriole is one of a lumen size about 30 micrometer, especially if it is precapillary (terminal arteriole, see Levick, 2003). 30 microme-

ters can fit in about 4 red cells. Our observations show that the villi vessels normally admit about 1 red cell, and with reference to the endoscopic features and at the magnification we saw, the vessels are of about 10-15 micrometers, more fitting to be the size of most capillaries. Thus we were prompted to try to confirm the actual nature and the size of the blood vessels in the human intestinal villus, by the use of transmission electron microscopy, supplemented by conventional tinctorial and modern immunohistochemical techniques, to correctly reveal their true nature, but since the latter two approaches may be less certain with vessels of such small size, electron microscopy (EM) is the mainstay of our study.

MATERIALS AND METHODS

With patient consent, samples of normal areas of the ileum in two human subjects were taken. Two samples from each of two patients (one a boy of 4 years which we will call patient X, and the other a woman of 66 years, patient Y), who underwent endoscopy investigations using a Fujinon 4400 processor and 590 colonoscope with optical zoom, enhanced by multiband imaging software (FICE – Fujinon Intellegent Color Enhancement) (Fujinon, Saitama, Japan) for their gastrointestinal complaints. Their samples were immediately fixed in cooled glutaldehyde solution, and processed for EM examination following the usually established protocol. The specimens were oriented so that villi were cut across or transversely, and for 3 levels, at about the top, middle and bottom of the villi. The semi-thin sections and ultrathin sections were observed at scanning and higher powers for details of the blood vessels in the villus core, their relative positions also noted. Another sample went through histological processing for light microscopy (LM), stained with haematoxylin and eosin stains (H & E), and by immunohistochemical methods for smooth muscle (Actin), and endothelial cell element (CD31 and CD34), and to detect for elastic element of the arteriole by traditional tinctorial stains (elastic van Giesen -- EVG, and Orcein). Subsequently, two more samples were obtained from two subjects undergoing ileal endoscopy examination who gave consent to have their normal areas taken. One was from a man of 49, patient M, and the other from a man of 57, identified as Patient N.

RESULTS

There is no apparent difference in the features of the villi between the two patients X and Y under LM and EM, and also with results from determination of the diameters of the vessels and measurements of the thickness of their walls (see below), using the EM sections. All EM sections for all 4 patients show no arteriolar structure, nor venular structure, at all sectional levels, throughout the whole cross-section of the villous cores examined. There is no suggestion of an arteriole present, such as large diameter (e.g. 20 to 30 micrometers) vessel size, with thick wall due to circumferential muscle layer (at least 1 layer) and elastic fibres in the internal area beneath the endothelium. The high power views show a sampling of the vessels in each level, and the vessels are capillary in nature, being simple, small diameter, with thin wall. We had measured in Patients X and Y, the thickness of the wall exclusive of the endothelial cell nucleus in these vessels, and they were around 0.5 micrometers. The circumference of the capillaries has been measured individually using a piece of string tracing along the interface between capillary basement membranes and the basal surface of endothelial cells (see Table 1). The diameters of capillaries are calculated. All values in micrometers. A few out of range results were excluded. The average capillary diameter of each case was calculated, the two are almost identical, being about 10 micrometers. By student's t-test analysis, two tail between the 2

Table 1. Villous circumference measurements and diameters in microns (4 out of range values not listed, capillary numbers were assigned at random).

Patient X	Circumference	Diameter	Patient Y	Circumference	Diameter
01	27.3	8.69	01	34.5	10.98
02	28.6	9.10	02	22.1	7.04
03	36.7	11.68	03	25.3	8.05
04	19.7	6.27	04	23.1	7.35
05	49.3	15.69	05	38.0	12.10
06	19.5	6.21	06	28.1	8.95
07	40.3	12.83	07	53.3	17.00
08	39.0	12.41	08	55.3	17.60
09	40.6	12.92	09	22.7	7.23
10	39.5	12.57	10	44.6	14.20
11	31.1	9.90	11	31.2	9.93
12	28.0	8.91	12	31.4	10.00
13	49.5	5.76	13	27.6	8.79
			14	26.6	8.47
			15	27.6	8.79
Average diameter = 11.00			Average = 10.43		

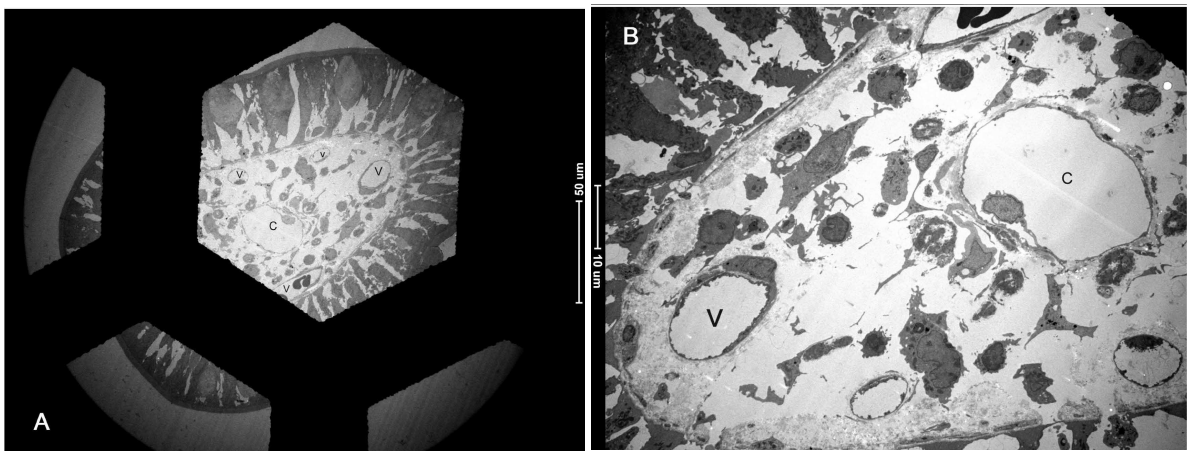

Fig. 2 (above). (A) Patient M. Scanning view of EM of a villus at level 2, i.e. at the middle the villus, showing a large part of the whole villus core in cross-section, with several blood vessels, (V). In another grid (not shown), the rest of the core was examined, to ensure that there are no arteriolar vessels missed. Note that in this and all subsequent EM figures, no vessel is anything near 30 µm in thickness of its wall, nor having a lumen near 30 µm diameter (points discussed in the text), except the central lacteal, (C). **(B)** Higher power EM view of the same villus core as (A). A vessel (V) is seen at about 8 o'clock position, with a single endothelial cell lining and a thin wall. This is a capillary vessel by ultrastructure. There is a pericytic cell around 12 to 2 o'clock position of its outer wall. The other vessels, as seen and labeled in (A) are also evidently capillary in nature.

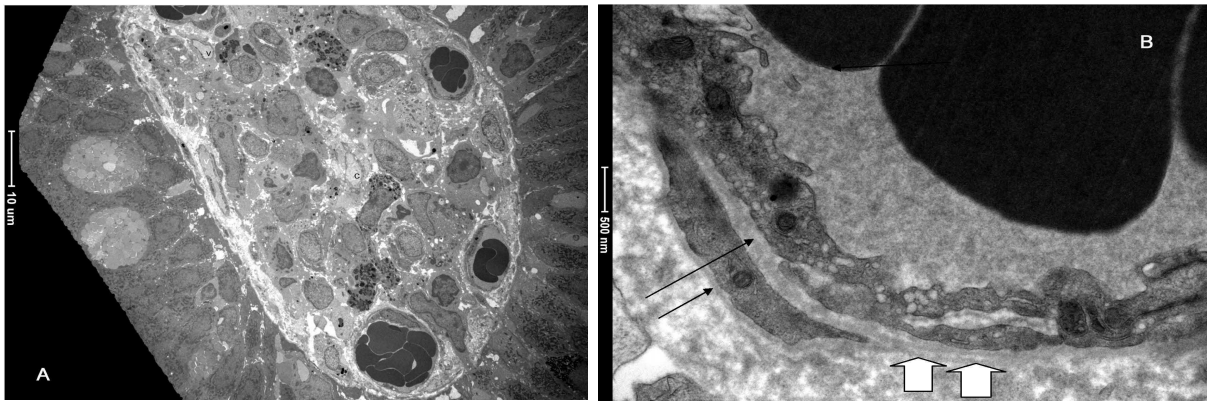

Fig. 3 (above). (A) Patient N. Scanning power EM view, level 3, whole villus core cross-section. There are simple capillary vessels, distended with red cells. There is a central vessel (c)**,** simple but collapsed. This is the central lacteal. Smaller vessels are seen (v) with no red cells. **(B)** Patient N. High power EM view of a capillary, showing prominent basal lamina; at 7 to 8 o'clock, it is split by an extension of an endothelial cell (arrows), with no evidence of elastic fibres. The basal lamina is duplicated in places (white arrows).

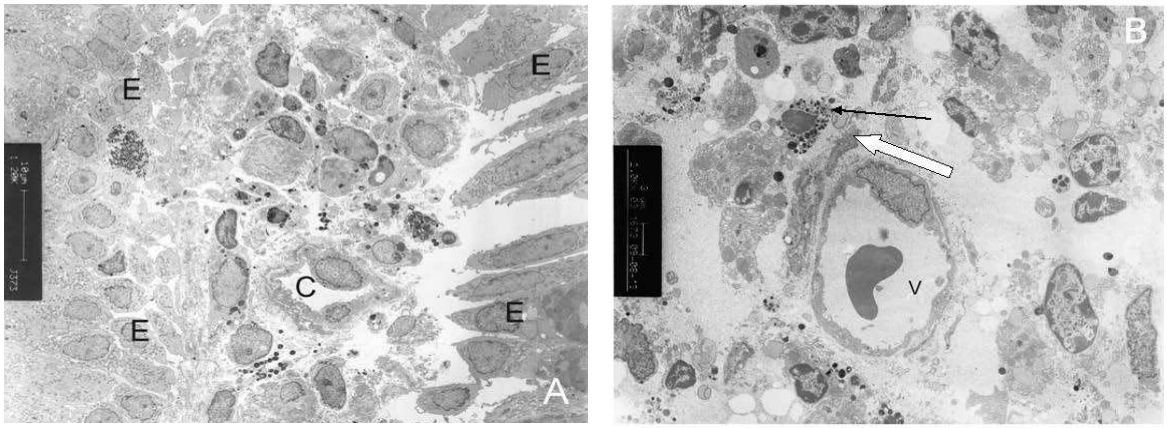

Fig. 4. (A) Patient X. Scanning view of EM of a villus at level 1, i.e. near the tip of the villus, showing a large part of the villus core, with several blood vessels (v) cut across. Villous epithelial cells (E) are seen across the top of the picture. **(B)** Patient X. High power EM view of a vessel (V) at level 1. The vessel is simple, with a single endothelial cell lining and a thin wall. This is a capillary vessel by ultrastructure. The nucleus of the endothelial cell is furthest away from the epithelial cells at the right lower side of the photo. The diameter of the vessel admits about 2 red cells. There is a phagocytic cell (arrow) around the upper part of the capillary. A thinned cell between may be a pericyte (white arrow).

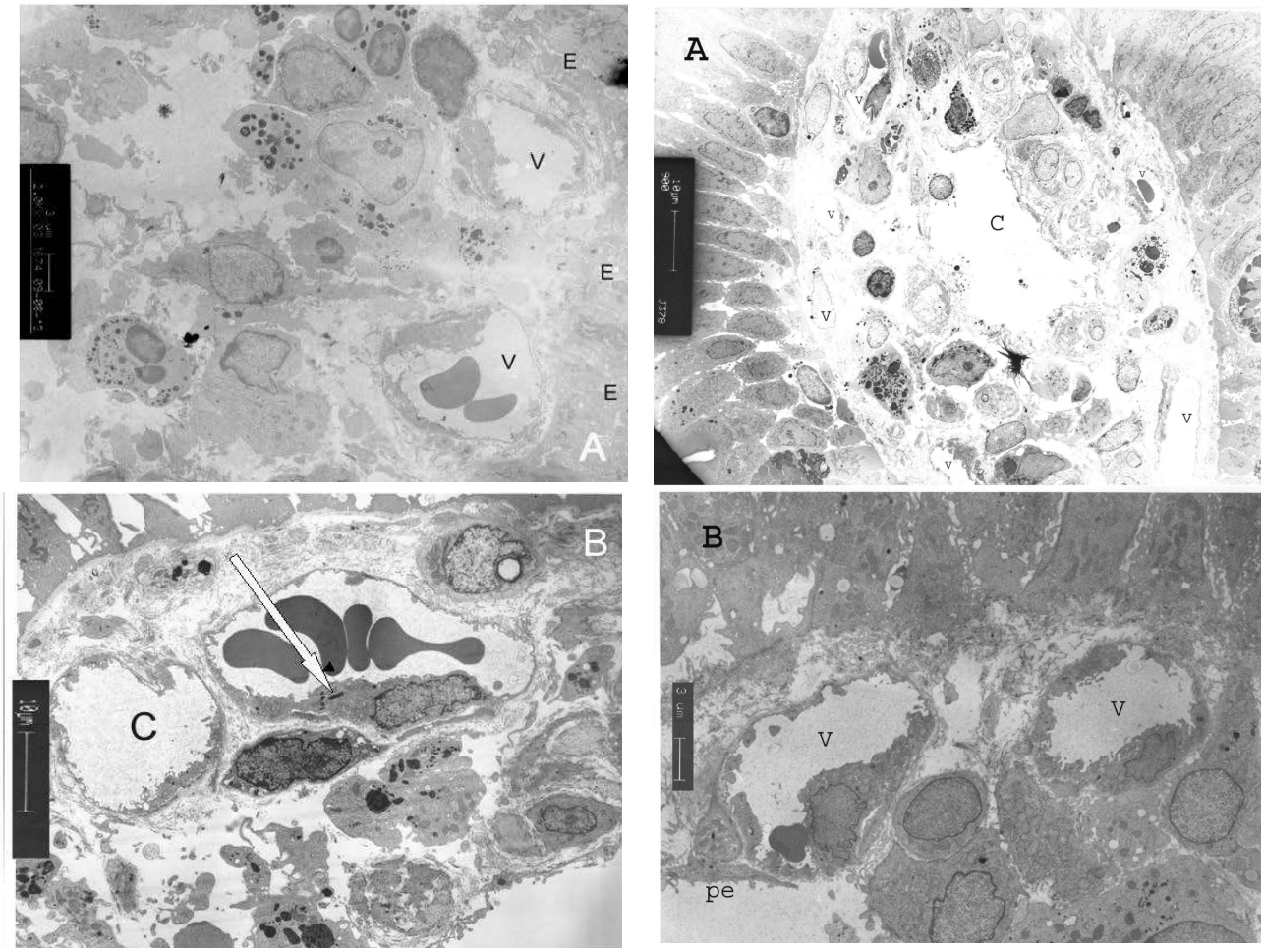

Fig. 5 (left). (A) Patient Y. Scanning power EM view, level 2: whole villus cross-section, with epithelial cells (E) almost all around the core. There is a central vessel, simple but collapsed. This may be the central lacteal (C). **(B)** Patient Y - Higher power EM view, level 2, showing a distended capillary, with an endothelial cell, and another capillary next to it. Note again the nuclear position, on side furthest from the epithelial cell. Note Weibel-palade body in the endothelial cell of the elongated capillary (arrow), with several red blood cells in a line. This capillary is probably cut almost horizontally, being a crossing capillary between the legs of the loop pattern villus (see text; also, this is one of the out of range diameters on measurement of the circumference and calculation, noted in Table 1).

Fig. 6 (right). (A) Patient Y. Scanning power EM view of whole cross-section of a villus at level 3, with subepithelial capillaries (V); the lumen in the middle is the central lacteal (C). **(B)** Patient X. High power EM view at Level 3. There are two capillaries (V) in the subepithelial position, the one in the lower part of the photomicrograph shows a pericytic cell (pe) outside the basement membrane of the vessel.

cases show no difference, p value around 0.5.

All capillary channels seen are of the fenestrated type, and in almost all the capillary channels next to the epithelial cells, their endothelial nuclei, hence the bulk of the cell material, are on the far side of the epithelial surface, i.e. the nuclei are on the luminal surface of the vessel towards the centre of the villus. Figs. 2A through to 3B are EM photos from the patients M and N. Figs. 4A through to 6B are from patients X and Y. Details are in the legends of these figures.

From patients X and Y, sections for LM show, with conventional histochemistry stain for elastic element in the villus vessels are negative, so are immunohistochemistry staining for smooth muscle cells around these vessels. There are positive Actin stain in the villus, and are either smooth muscle fibres that run longitudinally in the core of the villi, or are only in the periphery of the vessels. These latter probably stained for pericytes, or Roughet cells, of the capillaries. This positive staining is to be interpreted in the light of the EM findings, and also of the negative results for elastic element in the vessels (Figs. 7 to 8).

DISCUSSION

The vascular architecture of the human intestinal villi should be pertinent to the physiological requirements of body development to subserve the absorptive and digestive functions of the small intestine. The villi enormously increased the surface

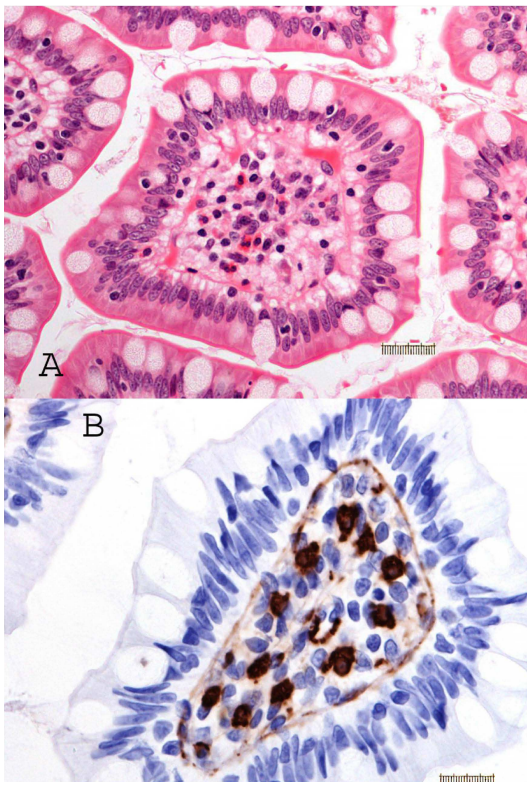

Fig. 7 (left). (A) Light microscopy (LM) photomicrograph. There is a whole villus in cross-section amongst others that are partially seen. There are small blood vessels mostly subepithelially, and there is no large thick-walled blood vessel in the core. H & E stain. Scale: 40 µm. **(B)** LM photomicrograph of whole villus in cross-section. This is an immunohistochemical stain for Actin, labelling smooth muscle cells, which are apparently all cut across, and shows no positive staining cell that is around a vascular lumen such as an arteriole. Scale: 40 µm.

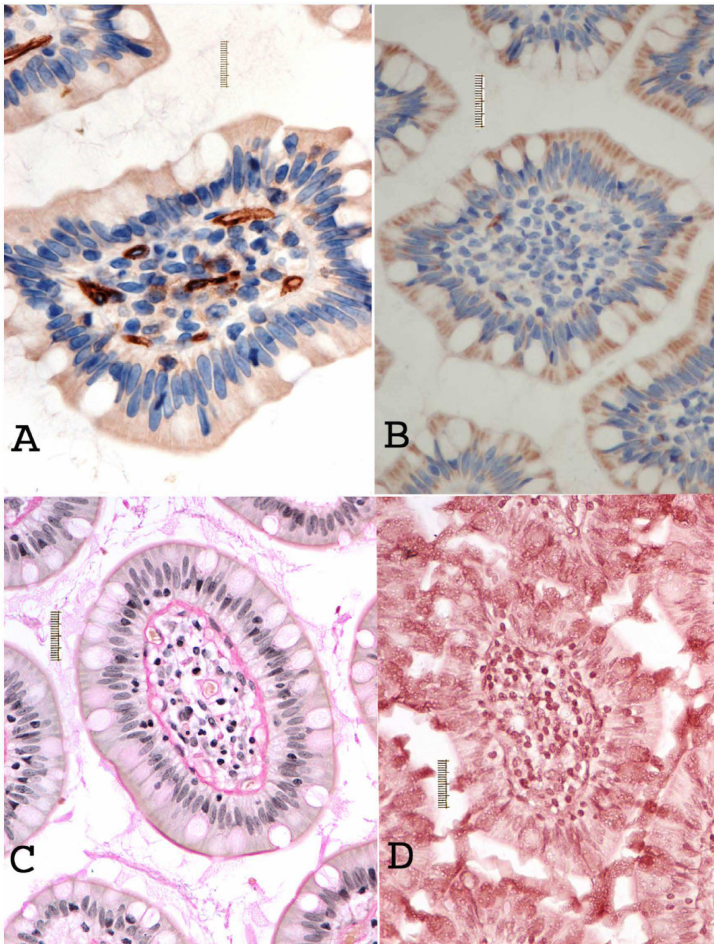

Fig. 8 (right). (A) LM photomicrograph of whole villus in cross-section. This is an immunohistochemical stain CD31, staining for endothelial cells; note that this staining outlines structures with a lumen, interpreted as being capillaries, in view of findings in Fig. 7B. Scale: 40 µm. **(B)** CD34 immunohistochemistry staining for endothelial cell, again note those outlining the blood vessels, which are structurally simple and are capillaries. Scale: 20 µm. **(C)** EVG stain, a conventional tinctorial connective tissue stain: elastic is black, and collagen is reddish. There is no elastic staining associated with the vessels with red cells. Scale: 40 µm. **(D)** Orcein stain, another conventional tinctorial stain. There is no black staining for elastic material/tissue. Scale: 40 µm.

area for these functions to be effected with high efficiency (see Madara and Trier, 1987; Patton and Thibodeau, 2010). Thus, there is a functional requirement for the blood supply, carrying nutrients, catalysts and energy (including oxygen, through the red blood cells, as direct energy), to be transported to the functional surface of absorptive and digestive cells. The shorter that distance, the sooner would the energy reach these cells, with least of waste or resistance on the transport path, and for the oxygenated or energy rich blood to transfer these contents to the epithelial cells sooner, the arterial blood can immediately unload its content if it is a capillary channel starting from the bottom of the villus. This physiological function will be less efficient if an arteriole goes to the tip first, whether it is in a fountain pattern, or step-ladder pattern, bearing in mind that an arteriole, or venule for that matter, cannot subserve these functions better than the capillaries (Granger et al., 1988), if indeed they can subserve such functions at all – a mistaken concept by a number of authors, who purported to have seen arterioles and venules in the villi, and went on to say that these vessels can perform such exchange functions. Thus, there is a mechanical advantage for the vascular supply of capillaries to be following a reverse-fountain or funnel-drain pattern, or a loop pattern, rather than through a fountain pattern. Correlated with such an arrangement, even the endothelial cells of the capillaries show their nuclei towards the villus centre, thus, the blood plasma and red cells have the

shortest distance and least obstruction towards the epithelial cells. Such an endothelial cell arrangement in the capillaries had been amply reported in all species (Casley-Smith, 1971; Abbas et al., 1989; Madara and Trier, 1987). Our findings, together with the convincing endoscopic observations of Leung (2013) about the vascular patterns, concur with the idea that these villus vessels are all capillaries or with a meta-arteriole (Kelley et al., 1984; Cormack, 1993) and not true arterioles. The step-ladder pattern, of course, had been described in man by Frey (1876), Henle (1873) and by Testut (1923), which we can now interpret as similar to our loop pattern, but these early authors said there is an arteriole and venule that constitute the loop of the ladder pattern, and we question the validity of such statement as the observations were not in the living, and not proven by scanning electron microscopy on the vascular casts.

The loop arrangement also indicated the possibility of counter-current exchange, and this works whether it is a reverse-fountain pattern, or loop pattern. Although the existence of such counter-current exchange is somewhat controversial (Bohlen and Lash, 1995; Bond et al., 1977; Shepherd and Kiel, 1992), but if there is an arteriole and venule that form the loop, no effective counter-current exchanges can take place. This is not only due to the fact of the thickness of vessel walls (of the arteriole and venule), but also the high flow rate in these vessels(Anthea et al., 1993); although some exchange may take place, given there are differences between species, these vessels (the arterioles and venules) are too thick and are not constructed for exchange functions (Leeson et al., 1985; Granger et al., 1988; Shier et al., 2004) with the exception of gaseous exchange, including oxygen, which works through diffusion, and which can apparently pass through these vessels (Tsai et al, 2003).

Further, Leung observed a low flow velocity of red cells (around 1 mm/s) in the villus vessels, and they have a diameter smaller than the arterioles (Leung, 2013a). A recent work on the mouse measured flow velocity in the vessel at the villus tip; this villus tip vessel the authors said was an arteriole and got a result of 0.15-1.25 mm/sec (Nakajima et al., 2001); this is not an arteriole flow rate, which averages 1.66 mm/sec. and are often higher (Table 2). The capillary velocity they obtained were 0.10-0.55 mm/ sec., figures that overlap greatly with their “arteriole” rates, whilst other authors got capillary rates of 0.03-0.9 mm/sec., depending on different species and under different conditions (Table 2). Flow rate considerations have also physiological implications – the velocity should be slow enough for full exchange to take place, and it had been established that the rate should be in the order of tenths of a second (Sarelius et al., 1981; Wagner, 1977). From another angle, a flow velocity curve diagram, such as that seen in Vander’s Human Physiology (Widmaier et al., 2006), shows a precipitous fall in rate from the arteriole side to the capillary, which means that the low rate observed by Nakajima et al. (2001) in their “arteriole” is probably that of a capillary instead of a true arteriole. There are otherwise few reports on the rate of arteriolar flow, but Yates (1991) tabled some parameters in the dog, and quoted an arteriole rate of 6 mm/s, which is a velocity more in line with the flow velocity curve diagram of Vander, in contra- distinction from the low rate reported by Nakajima et al. (2001). In Yates’ paper, it was also noted that the dog parameters are probably true for all mammals regardless of size, thus it may be a rate also in the human, thus, the villus vascular flow rate Nakajima et al have observed was not that of an arteriole at all. They have presumed, that the villus tip vessel is an arteriole because such a notion had been passed down in the medical literature without re-examination.

Table 2. Blood flow velocities in capillaries and arterioles. (Average or peak, range in brackets, stated in mm/sec)

References	Source species	Organ or site	Velocity in Arteriole	Velocity in Capillary
Bevan	Various	not specified	3-30	--
Milnor	Cat	various	9	0.7
Yates	dog@	not specified	6	--
Nakajima	mouse	intestinal villus	1.25(control); (0.15 - 1.2)	0.55(control); (0.1 - 0.61)
Koutsiaris	Human	Conjunctiva	1.66 (0.52-3.26)	--
Goerke and Mines	Human	Overall	2.10	0.19
Shih	Rat	cerebral cortex	surface (1.4 - 34)	
			penetrating (0.7 - 35)	
Seylaz	Rat	Brain		0.39 plus/minus 0.27
Caro	Dog	Cardiovascular	(5 - 10)	(0.2 - 1.7)
Caro, quoting others			(0.8 - 31.7)	(0 - 1.7)
Nuttall	guinea pig	cochlea*	0.27 in "feeder vessel"	(0.08 - 0.12)
Nuttall, quoting others			(0.305 - >1.0)	(0.06 - 0.17)

*cochlea velocities are slower than in other sites. @ it is thought that figures are applicable to other mammals also

One final observation: the usually accepted figure for the total diameter of a terminal arteriole is 30 micrometer, half of which is the lumen diameter, half of which is two times the thickness of the muscular wall (Levick, 2003). The cross sectional diameter of a finger-like villus is up to 250 micrometers, thus, in our cross sections, we should see at least one vascular structure that occupies about 1/4 to 1/3 diameter of the core, but there were none in all our samples, excluding the central lacteal. Yet, there are reported arterioles of about 15 µm overall diameter elsewhere, but they are thick-walled, with several endothelial cell nuclei, and a distinct ring of smooth muscle cells (see Caro et al., 2012, Fig.13.5, p.352), distinctly different from the capillaries that we have seen and demonstrated.

Although by our observations and also by the above arguments, we have a strong case for stating that the villus vasculature is composed of capillaries (and may be with a meta-arteriole), through electronic microscopy and conventional histology, we have not done corrosion casting and examination by scanning electron microscopy to look at the arrangement of the endothelial cells, as further support to our diagnosis; thus, we have also not determined the vascular architecture or pattern by another route, viz., we have not done a 3 dimensional reconstruction, for the villus core vascular network pattern, and our sampling is limited. However, Leung (2013) had convincingly discovered about the most often seen patterns in his *in vivo* endoscopic studies that included the flow directions. Following this communication, we hope to be able to do the other studies as suggested above, or other investigators would be motivated to take up these works.

We have limited our thinking, and observations to the human subject. In animals, some findings suggest existence of a predominantly fountain pattern instead, at least in some species (Bellamy et al., 1973; Jacobson and Noer, 1952; Miller et al., 1969). Such findings, though are contradictory to our thinking from the physiological perspective, we are of the opinion that we cannot directly extrapolate our thinking on humans to the animal subjects. Also, these are earlier works before scanning electron microscopy. However, in the mouse, there is also only a capillary component, possibly showing a tuft or step-ladder pattern (Abbas et al., 1989; Hashimoto et al., 1999).

During the course of writing up this article, we read a good number of reference or semi-reference material, in order to see how the human villus vascular architecture is reported (except for those referred to specifically below, a list is appended, as Supplementary Material, of these books or source material for those readers interested). First, we have come to note that there is a relatively recent series of articles (one example, Gannon et al., 1980), on the human intestinal villi. These reported that the human villi are like those of the rabbit, and like that reported by Jacobson and Noer (1952). In these articles, the arteriole and venule sizes are about 20 microns according to the scale given. We question the finding of arteriole and venule, on the same grounds as we had proposed above, and also, a photomicrograph had shown a vessel labeled as arteriole, which seemed to us to be a simple vessel and have a thin wall, unlike a true arteriole. Corrosion cast nuclear impressions of capillaries are like the arterioles, and, if the vessel is dilated to 20 micrometers (which is at all possible in a capillary or in a meta-arteriole), we wonder if the nuclei could become no longer in a line and thus, simulate the arteriole character more. It is also not known if the blood flow character had been noted, viz. pulsatile (arterial) or vasomotion (capillary) in their vessels. Only one article (Karelina, 1978), definitely said that the architecture is composed of capillaries only, in unison with our findings. The work was also by corrosion cast technique. This is also true of the book by Meschan (1975). Another paper also contrasts other reports, and noted a vascular network of capillaries subepithelially, but with a central vein, and an eccentric arteriole going up to half of the length of the villus (Swan et al., 1978). Secondly, in reference books and textbooks for the medical community, some described the villus with fountain pattern, or loop pattern, or with no mention of pattern, but said the villus has arterioles and venules. Almost all of the above have drawings of the villus, illustrating the vascular supply by a red vessel labeled “arteriole” (or “artery”), and drained by a blue vessel labeled “venule” (or “vein”), and mostly with a step-ladder pattern. Sometimes, an “arteriovenous capillary network” is said to be present in the villus core. Some others described the villus core as showing capillaries (or occasionally just “vascular”), with no mention of arteriole or venule. However, in these, many have drawings that illustrate the villus, with a vascular supply that similarly show labeled, colored “arterioles” and “venules”, contradicting their own text. The most important point to note of ALL these works is, whatever is said in the text, or illustrated in the drawings, where they have photomicrographs, no arteriole or venule is labeled, because none is there to be seen to label. This is exactly what we found in our current results. Sometimes, non-human material is quoted in teaching books on human histology and anatomy. Commercial models of villi (for high school teaching and the common public) almost always show an arteriole and a venule besides capillaries. One current website, however, displaying a version also of Gray’s Anatomy, the old classic textbook of anatomy for medical students for over a century, does have illustrations, photomicrographs and text, that does not indicate the presence of an arteriole in the intestinal villus (Theodora.com, 2013).

In conclusion, our work had shown, with anatomical and physiological support, convincing evidence that whatever the villous microvascular pattern may be, there is no arteriole in the villous core. Our findings are supported also but by a few workers only. There is a lack of consensus and varied descriptions in the human intestinal villus vascular architecture. We hope that our findings may direct attention to some uniformity towards what the true state is, apparently useful in the realm of knowledge dissemination, and we believe our observations may start the road to this uniformity.

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