Anat Sci Int (2010) 85:23–30
DOI 10.1007/s12565-009-0047-9

ORIGINAL ARTICLE

An investigation of human jejunal and ileal arteries

Dylan Conley · Peter R. Hurst · Mark D. Stringer

Received: 14 March 2009 / Accepted: 7 May 2009 / Published online: 3 June 2009

Abstract The arrangement of jejunal and ileal arteries varies along the length of the small bowel, but the reasons for this and the functional implications are uncertain. The aims of this anatomical and histological study were to investigate quantitative differences between jejunal and ileal arteries and to investigate their relative muscularity. Ten cadaver small bowels (five males, mean age 78 years) were analysed. In each specimen, the mesentery of two standardised 40-cm lengths of jejunum and ileum were dissected and measured. Representative arterial samples from a jejunal and ileal parent artery, first arcade artery and arteriae recta were examined histologically and their relative muscularity (proportion of arterial cross sectional area occupied by tunica media) compared. No consistent differences were found between jejunal and ileal parent artery lengths, but jejunal arteries tended to be larger (mean diameter 2.2 ± 0.2 mm vs. 2.0 ± 0.4 mm, $p = 0.08$). Compared to the jejunum, the number of arterial arcades was significantly greater in the ileum ($p < 0.0001$), and the arteriae recta were more numerous ($p = 0.02$), shorter ($p = 0.007$) and narrower ($p = 0.004$). There was no statistically significant difference between the muscularity of proximal jejunal versus distal ileal arteries or between parent, first arcade and arteriae recta within the proximal jejunum and distal ileum. These quantitative data clarify conflicting statements about jejunal and ileal arterial anatomy. However, the different arterial pattern in the jejunum and ileum does not appear to be associated with differences in the muscularity of these arteries.

Keywords Mesenteric arteries · Small intestine · Splanchnic circulation

Introduction

The gross anatomy of small bowel arteries has previously been investigated by a variety of methods including cadaver dissection (Beaton and Anson 1942; Michels 1955), in vivo angiography (Nebesar et al. 1969) and post-mortem injection studies (Cokkinis 1930; Noer 1943). Jejunal and ileal arterial branches from the superior mesenteric artery (SMA) fan out within the small bowel mesentery and divide into two, each branch communicating with a branch from the artery above or below. A series of arterial arcades are formed. The number of tiers of arcades varies between the jejunum, where there are typically one or two, and the ileum, where there are often three to five (Standring 2008). Multiple vasa recta pass between the most distal arcades and the wall of the jejunum and ileum.

The jejunal and ileal arteries, arcades and arteriae recta are known to be muscular arteries consistent with the fact that splanchnic blood flow can vary between 10 and 35% of cardiac output (Rosenblum et al. 1997). However, there are no data on the relative muscularity of these arteries. If this was to differ, it might be linked to the currently unexplained differences in the pattern of arcades and arteriae recta between the jejunum and ileum. The aims of this study were firstly to obtain quantitative data on jejunal and ileal arteries and secondly to investigate the relative muscularity of these arteries.

D. Conley · P. R. Hurst · M. D. Stringer (✉)
Department of Anatomy and Structural Biology,
Otago School of Medical Sciences, University of Otago,
913, Dunedin, New Zealand
e-mail: mark.stringer@anatomy.otago.ac.nz

Methods

Cadaver specimens and quantitative gross anatomy

The entire jejunum and ileum with attached mesentery were removed from ten cadavers [five males, mean age 78 (66–93) years] bequeathed to the Department of Anatomy and Structural Biology at the University of Otago under the New Zealand Human Tissue Acts (1964, 2008). Two cadavers had been embalmed using Dodge Anatomical mix (Dodge Anatomical, Dodge Co., Boston MA) and the remainder with phenoxyethanol mix (Nicholson et al. 2005). None had evidence of previous small bowel pathology or surgery. The length of each small bowel was measured along its antimesenteric border.

In each specimen, the mesentery of two standardised 40-cm lengths of bowel was dissected to expose the mesenteric arteries; the jejunal segment extended from 20 to 60 cm distal to the duodenojejunal flexure and the ileal segment from 20 to 60 cm proximal to the ileocaecal junction (Fig. 1). The following were recorded in each 40-cm length of jejunum and ileum in all ten specimens: the length of the mesentery (from the SMA to the mesenteric border of the mid-portion of bowel); the length of all jejunal and ileal parent arteries (branches from the SMA to the first arterial arcade); the total number of complete anastomotic rings within the arcades; the total number of arteriae recta. Each 40-cm length of jejunum and ileum was then divided into a proximal and distal section (each measuring 20 cm in length), and two further measurements were made: the minimum and maximum number of tiers of arterial arcades passed through in a straight line from the SMA to the bowel and the length of ten randomly selected arteriae recta (Carbon Fiber Composites Digital Caliper, Ted Pella, Inc., Texas; accuracy ±0.2 mm). All measurements of arterial arcades and arteriae recta were repeated blindly in two specimens by two investigators (DL and MDS) to assess intra-observer and inter-observer variability.

Histology

From the proximal 20 cm of each jejunal segment and the distal 20 cm of each ileal segment, a section of artery measuring up to 5 mm in length was excised from the mid-region of a parent artery (PA), first arcade artery and arteriae recta (AR). A parent artery was defined as a jejunal or ileal artery branching directly from the SMA, a first arcade artery was the first artery nearest the PA that was part of a complete anastomotic ring, and arteriae recta were arteries that ran directly between the most distal arterial arcade and the wall of the small bowel. Arterial samples were post-fixed in 10% neutral buffered formalin, embedded in paraffin, sectioned transversely (3 μm), stained with haematoxylin and eosin and Verhöeff–Van Gieson, and examined by light microscopy (Olympus AX70, Olympus Optical Co., Ltd., Japan). Photomicrographs and scale bars were taken at set magnifications using a Spot RT colour camera (model 2.2.1, Diagnostic Instruments Inc., USA) and the MicroPublisher 5.0 RTV Q imaging system (JH Technologies, USA).

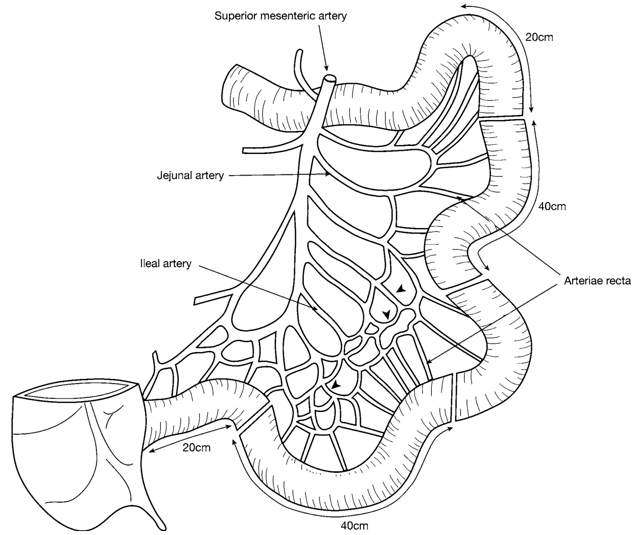

Fig. 1 Diagrammatic illustration of the jejunal and ileal segments that were dissected showing the parent jejunal and ileal arteries, arterial arcades (*arrowheads*) and arteriae recta

The freeware program ImageJ (National Institutes of Health, USA) was used to measure diameters and cross-sectional areas (CSA) in arterial photomicrographs. A "muscularity index" was devised to compare the relative muscularity of arteries (Fig. 2). This involved measuring the CSA of the artery within the external elastic lamina (or the well-defined boundary between the tunica media and adventitia in small muscular arteries lacking an external elastic lamina) and subtracting the CSA of the artery within the internal elastic lamina. The proportion of the artery's CSA within the external elastic lamina occupied by the tunica media could then be calculated. This method can be applied to arteries of different shapes and eliminates problems arising from subintimal atheromatous deposits. The diameter of the PA and AR was calculated from the formula:diameter $= 2 \times \left(\sqrt{\frac{A1}{\pi}}\right)$ which estimates the diameter of the artery, assuming that it was originally circular in cross section. Two sections from each arterial sample were analysed, taking the mean of both measurements.

The relative elastin content of the arteries was also compared in six specimens using a novel technique. A representative photomicrograph of each arterial section stained with Verhöeff–Van Gieson (same batch, identical

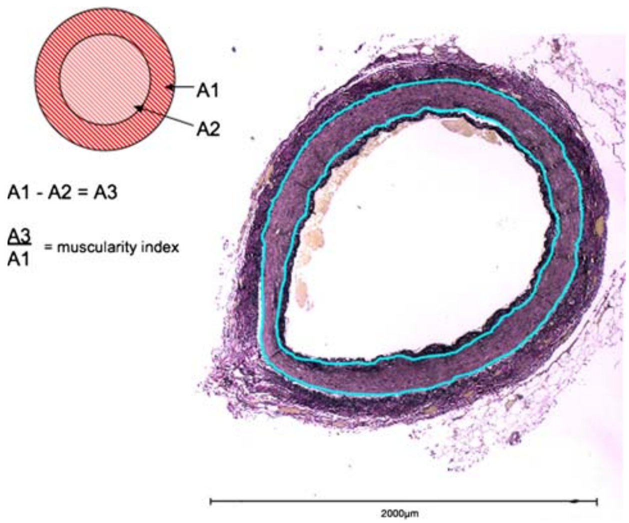

Fig. 2 Photomicrograph of a transverse section of an ileal artery stained with Verhöeff–Van Gieson for elastic fibres. The ImageJ draw tool was used to outline the internal and external elastic laminae (*blue*). The CSA of tunica media (*A3*) was derived by subtracting the CSA inside the internal elastic lamina (*A2*) from that inside the external elastic lamina (*A1*). The muscularity index was the proportion of the CSA of the artery within the external elastic lamina occupied by the tunica media (*A3*/*A1*)

Fig. 3 Excised doughnut of tunica media (Verhöeff–Van Gieson stain) rendered as a greyscale image prior to applying a standard threshold value for identification of elastin

protocol) was taken using the light microscope and imaging system described above, under the same conditions of illumination and magnification. Each image was imported into Adobe® Photoshop® (CS3, Version 10.0.1, Adobe Systems Inc., USA) and the tunica media "doughnut" between the internal and external elastic laminae precisely excised using the lasso tool. Each doughnut was then saved as a greyscale image in the tiff file format and imported into imageJ (Fig. 3). The image threshold was adjusted until all of the black-stained elastin in each doughnut was coloured red; this was found to correspond to a threshold of 0.75. This threshold value was applied to each image to yield the proportion of tunica media occupied by black-staining elastin.

Statistical analysis

Results were expressed as means ± standard deviations (SD) and compared using paired t tests with 95% confidence intervals (CI), taking $p < 0.05$ as statistically significant.

Results

The mean length of the jejunoileum in the ten cadavers was 3.81 m (range 2.76–4.77). The mean length of the ileal mesentery (125.6 ± 47.7 mm) was significantly greater than the jejunal mesentery (89.9 ± 13.9 mm; difference between means 35.7 mm, 95% CI 6.5–64.9, $p = 0.02$).

Comparison of mean jejunal and ileal parent artery lengths in each specimen showed no consistent differences. Although the overall mean length of parent ileal arteries (58.1 ± 36.9 mm) was greater than jejunal parent arteries (43.3 ± 13.1 mm), this difference was not statistically significant ($p = 0.25$). The number of tiers of arterial arcades in a straight line from SMA to bowel wall varied from one to three in the jejunum compared to one to six in the proximal ileal segment and two to four in the distal ileal segment. The mean numbers of complete anastomotic rings forming arcades in the 40-cm segments of jejunum and ileum were 9.4 ± 2.5 (range 7–14) and 24.7 ± 5.3 (range 12–31), respectively. This was a highly statistically significant difference (difference between means 15.3, 95% CI 11–19.6, $p < 0.0001$).

Data for mean AR length and total number of AR in the 40 cm segments of jejunum and ileum from ten cadavers are summarised in Table 1. There was a statistically significantly greater number of AR in the ileum, and these were shorter than in the jejunum. There were no significant intra- or inter-observer differences between repeated measurements. Calculated PA and AR diameters are shown in Table 2. The jejunal and ileal PA diameters were not statistically significantly different although there was a

Table 1 Summary of arteriae recta measurements in 40-cm lengths of jejunum and ileum in ten cadavers

Specimen no.	Mean arteriae recta length (mm)[a]				Total no. of arteriae recta	
	Proximal jejunal segment	Distal jejunal segment	Proximal ileal segment	Distal ileal segment	Jejunum	Ileum
0-287	22.6	31.2	20.5	23.2	62	51
0-255	27.2	26.2	19.4	19.6	53	58
0-270	26.3	29.3	15.2	15.4	44	63
0-291	23.9	24.1	21.4	23.7	38	39
0-277	26.3	28.3	26.3	25.3	38	53
0-307	29.3	27.8	31.4	31.8	76	81
0-334	28.8	28.8	16	20	34	60
0-369	30.9	28.9	22.4	23.8	37	52
0-348	29.3	29.7	22.2	16.6	52	64
0-285	24.7	24.3	22.6	22.4	52	57
Mean ± SD	26.9 ± 2.7	27.8 ± 2.3	21.7 ± 4.7	22.2 ± 4.7	48.6 ± 13.2	57.8 ± 10.9
p value	0.37		0.61		0.02	
Mean ± SD	27.4 ± 2.0		22.0 ± 4.5			
p value	0.007					

[a] Values in each specimen represent a mean from ten randomly selected arteriae recta

Table 2 Calculated diameters of jejunal and ileal parent arteries and arteriae recta

Specimen no.	Parent artery diameter (mm)		Arteriae recta diameter (mm)	
	Jejunum	Ileum	Jejunum	Ileum
0-287	2.30	2.40	0.89	0.59
0-255	2.20	2.20	0.69	0.54
0-270	1.90	1.30	0.74	0.61
0-291	2.30	1.50	0.71	0.45
0-277	2.30	2.30	0.92	0.72
0-307	2.50	2.50	0.51	0.70
0-334	1.90	1.85	0.71	0.46
0-369	2.50	2.07	0.72	0.51
0-348	1.99	2.01	0.94	0.42
0-285	2.32	2.18	0.88	0.55
Mean ± SD	2.22 ± 0.2	2.03 ± 0.4	0.77 ± 0.1	0.56 ± 0.1
p value	0.08		0.004	

statistical trend in favour of a slightly larger jejunal arterial calibre. Overall, jejunal AR had a significantly larger diameter than their ileal counterparts.

Table 3 summarises the data on the relative muscularity of the jejunal and ileal PA, first arcade artery and AR. There was no statistically significant difference between the muscularity index (proportion of arterial CSA occupied by the tunica media) of proximal jejunal versus distal ileal arteries or among parent, first arcade and AR arteries within the proximal jejunum and distal ileum. A typical sequence of jejunal arteries is shown in Fig. 4.

Results for the proportion of elastin stained by Verhöeff–Van Gieson within the tunica media of the arterial samples are shown in Table 4. The variability of results indicates that these data should be interpreted with caution, although AR tunica media appeared to contain a relatively higher proportion of elastin than more proximal arteries.

Discussion

Whilst the number of jejunal and ileal branches from the SMA has been recorded by various techniques in the cadaver and in vivo (Beaton and Anson 1942; Cokkinis 1930; Noer 1943; Michels 1955; Nebesar et al. 1969), anastomotic arcades and arteriae recta have rarely been

Table 3 Musculurity index data from jejunal and ileal arteries

Specimen no.	Parent artery muscularity index		First arcade artery muscularity index		Arteriae recta musculurity index	
	Proximal jejunum	Distal ileum	Proximal jejunum	Distal ileum	Proximal jejunum	Distal ileum
0-287	0.51	0.43	0.49	0.49	0.46	0.25
0-255	0.35	0.32	0.45	0.36	0.38	0.44
0-270	0.54	0.35	0.40	0.50	0.36	0.37
0-291	0.53	0.53	0.59	0.47	0.57	0.60
0-277	0.50	0.43	0.42	0.26	0.25	0.44
0-307	0.42	0.42	0.52	0.41	0.57	0.25
0-334	0.55	0.52	0.51	0.48	0.58	0.36
0-369	0.52	0.67	0.51	0.60	0.55	0.56
0-348	0.29	0.24	0.28	0.24	0.23	0.38
0-285	0.36	0.35	0.37	0.31	0.48	0.55
Mean ± SD	0.46 ± 0.1	0.43 ± 0.1	0.45 ± 0.1	0.41 ± 0.1	0.44 ± 0.1	0.42 ± 0.1
p value	0.28		0.16		0.68	

analysed quantitatively, and there appear to be no data concerning their relative muscularity or elastin content. Anatomical and surgical reference texts simply refer to the calibre of the ileal arteries as being smaller than the jejunal (Chevrel 1995; Standring 2008) and the jejunum as having one or two tiers of anastomotic arcades compared to three to five in the ileum. The AR are generally said to be shorter in the ileum (Chevrel 1995; McMinn 1998), but even this observation is variable with one well-known text describing them as longer and smaller in the ileum (Standring 2008).

Our study suggested that jejunal arteries have a slightly greater diameter than ileal arteries in the mesenteric sections analysed. There was no evidence of a graded decrease in arterial calibre from the jejunum to ileum as suggested by Beaton and Anson (1942) from their detailed study of a single cadaver. Parent ileal arteries were not shorter than jejunal arteries as stated in one modern text (Floch 2005); although this might be expected because of the greater number of arterial arcades in the ileum compared to the jejunum, the longer ileal mesentery compensates for this. Our study confirmed the greater number of arterial arcades in the ileum compared to the jejunum; Beaton and Anson (1942) previously noted that the arcades were smaller in the ileum. We also found a significantly greater number of AR in an equivalent length of ileum compared to the jejunum, and these ARs were significantly shorter and narrower. The shorter AR length in the ileum has been reported previously (Dwight 1903; Cokkinis 1930; Noer 1943), but the neat progressive diminution reported by Cokkinis (1930) was not evident. Further, we could only find one previous report comparing numbers of AR in the jejunum and ileum, and this related to a single cadaver specimen (Beaton and Anson 1942); these authors also found a greater density of AR in the ileum than the jejunum. Chiba and Boles (1984) counted total AR numbers in the whole small bowel, and, interestingly, their figure of between 393 and 452 is remarkably consistent with our data. Finally, our novel data on the relative muscularity and elastin content of proximal jejunal versus distal ileal arteries and parent artery versus first arcade artery versus AR showed no significant differences in these mesenteric segments, except for the possibility of a higher elastin content in AR compared to their feeding vessels.

The lack of a difference in relative muscularity between jejunal and ileal arteries and along their subdivisions is intriguing. Given the respective calibres of the parent artery and AR, this suggests that AR could play a major role in arterial blood distribution and that this is not necessarily dominantly regulated by the parent and arcade arteries upstream. Significant regulation of arterial perfusion at the level of the arteriae recta suggests that localised adjustments to arterial flow in the jejunum and ileum are important. In support of this, there is considerable evidence to show that localised hyperaemic responses occur in the small bowel in response to specific luminal contents (Granger et al. 1989). Our observations do not support the rather simplistic hypothesis that arterial elasticity is directly proportional to arterial proximity to the heart (Kumar 2001), a suggestion derived from a study of cadaver thoracic arteries. Indeed, our study suggests that AR may be more elastic than their feeding arteries, an unexpected finding that deserves further investigation.

Potential limitations of our study should be acknowledged. Firstly, our data were derived from elderly cadavers. Embalming may have affected the arterial structure, although Nicholson et al. (2005) found that satisfactory histology was obtained from cadavers using the embalming agents and techniques used in our study. Secondly, ageing itself (Sasajima et al. 1999) and systemic hypertension,

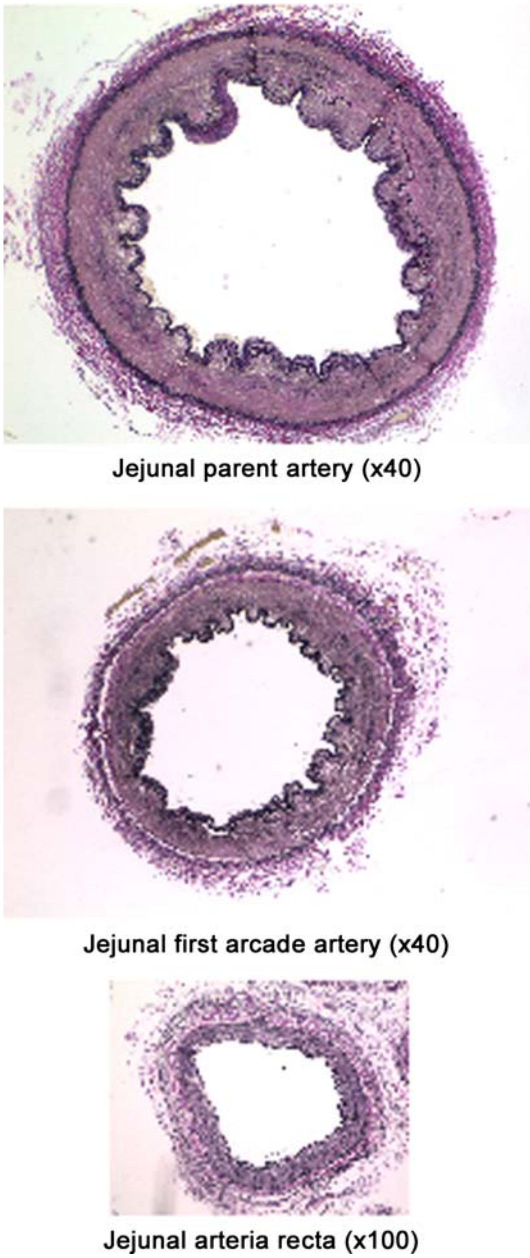

Fig. 4 A representative sequence of jejunal arteries along the mesenteric axis (Verhöeff–Van Gieson stain)

which is common in the elderly, can both cause an increase in peripheral arterial media thickness in experimental animals (Lee et al. 1983) and in humans (Mulvany 1996). However, neither age nor embalming would affect the numbers of vessels, and our data were controlled since we compared standardised jejunal and ileal arteries within individual cadavers. Further, comparing relative arterial muscularity by measuring the CSA of the tunica media and expressing this as a proportion of total arterial CSA, we avoided the problem of luminal distortion from subintimal atheroma and did not need a circular vessel outline for our calculations. Accuracy was enhanced by measuring duplicate specimens and checking for significant intra- and inter-observer variation. However, it should be noted that our findings relate to the proximal jejunum between 20 and 60 cm from the duodenojejunal flexure and to the distal ileum 20–60 cm proximal to the ileocaecal valve.

One of the aims of this study was to investigate the relative muscularity of jejunal and ileal arteries in the hope that this might shed some light on why the pattern of arterial arcades and AR differ between the jejunum and ileum. In other mammals, including dogs, cats and macaque monkeys, there are one or two tiers of arcades, but no regional differences between jejunal and ileal arteries (Sommerova 1980). In contrast, instead of arterial arcades, pigs have a narrow leash of anastomosing mesenteric arteries, which give rise to bundles of smaller arteries and then AR (Spalding and Heath 1987). Few theories have been put forward to account for the arrangement of arterial arcades and AR in humans. Various authors have suggested that since ARs do not communicate within the mesentery (Cokkinis 1930), the terminal arterial arcade provides a mechanism for maintaining collateral arterial blood flow during peristaltic contraction of the gut (McMurrich 1930; Ross 1952; Michels 1955). More often, a generic reference is made to the presence of numerous anastomotic arterial connections protecting the bowel under conditions of hypoxia and hypovolaemia (Hansen et al. 1998).

Other reasons may account for the arrangement of arterial arcades and AR in humans. The particularly close relationship between arteries and veins in the vasa recta at least may provide a counter current mechanism for local feedback mechanisms controlling blood flow. Such a mechanism may exist in human intestinal villi (Jodal and Lundgren 1986; Gannon and Perry 1989) and has been proposed as a possibility in the mesenteric vessels of pigs (Spalding and Heath 1987). However, this is unlikely to apply to the arterial arcades or proximal vessels where the arteries and veins are less closely associated. Whilst this hypothesis might explain the arrangement of vasa recta, it does not account for the arterial arcades. The existence of arterial arcades may be a device to maintain arterial perfusion of the gut if the mesentery is stretched or twisted, hence the need for more tiers of arcades in the ileum where the mesentery is longer. Stretching a straight artery would increase arterial resistance much more than stretching a series of tiered arcades. This hypothesis is supported by the fact that the sigmoid colon, a mobile part of the large bowel prone to stretching and twisting, has more arterial arcades than the remainder of the colon (Ross 1952). Another possibility is that the arterial arcade system modulates pressure and flow in the arterial bed. When arteries bifurcate, they give rise to daughter vessels whose total cross-sectional area is greater than that of the parent vessel, resulting in a drop in pressure and blood flow velocity

Table 4 Percentage of stained elastin in the tunica media of jejunal and ileal arteries

Specimen no.	Jejunal PA	Ileal PA	Jejunal first arcade artery	Ileal first arcade artery	Jejunal arteriae recta	Ileal arteriae recta
0-307	26	42	17	32	69	36
0-287	15	41	29	25	23	40
0-291	42	67	61	41	70	69
0-270	25	11	15	4	43	23
0-277	45	23	31	35	33	35
0-255	14	12	11	8	16	19
Mean ± SD	27.7 ± 13.1	33.0 ± 21.7	27.2 ± 18.3	24.1 ± 15.3	42.4 ± 23.0	37.1 ± 17.5
p values	0.55		0.55		0.50	

Jejunal PA versus jejunal first arcade artery, $p = 0.93$

Ileal PA versus ileal first arcade artery, $p = 0.15$

Jejunal AR versus jejunal first arcade artery, $p = 0.14$ (vs. jejunal PA $p = 0.3$)

Ileal AR versus ileal first arcade artery, $p = 0.02$ (vs. ileal PA $p = 0.2$)

(Mabotuwana et al. 2006). There appears to be little data on pressure changes within the human mesenteric arterial bed (Christensen and Mulvany 2001). In vivo studies in swine (which may not be a good model for humans for the reasons outlined previously) demonstrate a substantial mean arterial pressure drop from the mesenteric arterial trunk (about 70–80 mmHg) to the distal terminal mesenteric artery (about 40 mmHg) (Reber and Nowicki 1998). A similar pressure reduction may be important in humans. Finally, a greater number of arcades may simply facilitate greater flexibility in the distribution of arterial blood flow to the intestine, which may be more relevant in the ileum than in the jejunum where the majority of digestion occurs.

In conclusion, the quantitative data on jejunal and ileal arteries clarify previous conflicting statements about jejunal and ileal arterial anatomy. Jejunal arteries tend to be slightly larger than ileal, but the number of arterial arcades in the ileum is greater. Ileal arteriae recta are more numerous, shorter and narrower than in the jejunum. The different arterial pattern in the mesentery of the jejunum and ileum does not appear to be associated with differences in the muscularity of these arteries.

Acknowledgments We wish to acknowledge the assistance of Mandy Fisher of the Histology Services Unit; Robbie McPhee, Medical Illustrator/Graphic Artist for Fig. 1; Andrew Gray of the Biostatistical Support Service, Department of Preventive and Social Medicine, Dunedin School of Medicine, for statistical advice; and Andrew McNaughton at the Otago Centre for Confocal Microscopy for his expertise in developing the macro programme for determining the relative elastin content of the tunica media.

References

Beaton LE, Anson BJ (1942) The arterial supply of the small intestine. Quart Bull Northwestern Univ Med Sch 16:114–122

Chevrel JP (1995) Anatomy of the jejunum and ileum. In: Wastell C, Nyhus LM, Donahue PE (eds) Surgery of the esophagus, stomach, small intestine, 5th edn. Little Brown, Boston, pp 784–790

Chiba T, Boles ET Jr (1984) Studies on the relationship between the number of arteriae rectae of intestinal artery and intestinal length. Tohoku J Exp Med 143:27–31

Christensen KL, Mulvany MJ (2001) Location of resistance arteries. J Vasc Res 38:1–12

Cokkinis AJ (1930) Observations on the mesenteric circulation. J Anat 64:200–205

Dwight T (1903) The branches of the superior mesenteric artery to the jejunum and ileum. Anat Anz 23:184–186

Floch MH (2005) Vascular supply and drainage of the small intestine. In: Floch MH, Floch NR, Kowdley KV, Pitchumoni CS, Rosenthal RJ, Scolapio JS (eds) Netter's Gastroenterology. Icon Learning Systems, New Jersey, pp 306–308

Gannon BJ, Perry MA (1989) Vascular organization of the alimentary tract. In: Schultz SG (ed) Handbook of physiology. The gastrointestinal system Sect. 6. Vol. 1. Part 2. American Physiological Society, Bethesda, pp 1301–1334

Granger DN, Kvietys PR, Korthuis RJ, Premen AJ (1989) Microcirculation of the intestinal mucosa. In: Schultz SG (ed) Handbook of physiology. The gastrointestinal system Sect. 6. Vol. 1. Part 2. American Physiological Society, Bethesda, pp 1405–1474

Hansen MB, Dresner LS, Wait RB (1998) Profile of neurohumoral agents on mesenteric and intestinal blood flow in health and disease. Physiol Res 47:307–327

Jodal M, Lundgren O (1986) Countercurrent mechanisms in the mammalian gastrointestinal tract. Gastroenterology 91:225–241

Kumar K (2001) Microstructure of human arteries. J Anat Soc India 50:127–130

Lee RM, Garfield RE, Forrest JB, Daniel EE (1983) Morphometric study of structural changes in the mesenteric blood vessels of spontaneously hypertensive rats. Blood Vessels 20:57–71

Mabotuwana TDS, Cheng LK, Smith NP, Pullan AJ (2006) Modeling blood flow in the gastrointestinal system. Conf Proc IEEE Eng Med Biol Soc 1:1810–1813

McMinn RMH (1998) Last's anatomy regional and applied, 9th edn. Churchill Livingstone, Edinburgh, p 337

McMurrich JP (1930) In: Huber GC (ed) Piersol's human anatomy, 9th edn. JB Lippincott, Philadelphia

Michels NA (1955) Blood supply and anatomy of the upper abdominal organs: with a descriptive atlas. Pitman Medical Publishing, London, pp 280–293

Mulvany MJ (1996) Peripheral vasculature in essential hypertension. Clin Exp Pharmacol Physiol 23:s6–s10

Nebesar RA, Kornblith PL, Pollard JL, Michels NA (1969) Celiac and superior mesenteric arteries: a correlation of angiograms and dissections. Little Brown, Boston

Nicholson HD, Samalia L, Gould M, Hurst PR, Woodroffe M (2005) A comparison of different embalming fluids on the quality of histological preservation in human cadavers. Eur J Morphol 42:178–184

Noer RJ (1943) The blood vessels of the jejunum and ileum: a comparative study of man and certain laboratory animals. Am J Anat 73:293–334

Reber KM, Nowicki PT (1998) Pressure and flow characteristics of terminal mesenteric arteries in postnatal intestine. Am J Physiol Gastrointest Liver Physiol 274:290–298

Rosenblum JD, Boyle CM, Schwartz LB (1997) The mesenteric circulation. Surg Clin N Am 77:289–306

Ross JA (1952) Vascular patterns of small and large intestine compared. Br J Surg 39:330–333

Sasajima T, Bhattacharya V, Wu MH, Shi Q, Hayashida N, Sauvage LR (1999) Morphology and histology of human and canine internal thoracic arteries. Ann Thorac Surg 68:143–148

Sommerova J (1980) Contribution to the comparative anatomy of jejunal arcades in mammals. Folia Morphol 28:282–285

Spalding H, Heath T (1987) Arterial supply to the pig intestine: an unusual pattern in the mesentery. Anat Rec 218:27–29

Standring S (2008) Gray's anatomy. The anatomical basis of clinical practice, 40th edn. Elsevier, Philadelphia, pp 1128–1131