

## Anatomical structure and size of large intestinal mucosa in selected species of shrews and rodents

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The large intestine of eight Micromammalia species, of the orders Insectivora (*Sorex minutus*, *Sorex araneus*) and Rodentia (*Sicista betulina*, *Clethrionomys glareolus*, *Microtus oeconomus*, *Apodemus flavicollis*, *Mus musculus*, *Cavia porcellus*) were studied. Both the length and surface area of the mucosa of the alimentary canal are strongly associated with food hydration. In *M. oeconomus*, feeding exclusively on green parts of plants, the large intestine dominates the total length of the alimentary canal (35% of length). In omnivorous *S. betulina* and *A. flavicollis*, the length of the large intestine is 30% of total length of the canal and only 20% in *M. musculus* fed with dry and granulated food. The large intestine of the rodents (but *S. betulina*) is divided into caecum, colon and rectum. The caecum is best developed in *M. oeconomus*, where the relative value of the caecum is 5.54 mm/g and the surface area is 97.07 mm<sup>2</sup>/g of the body weight and least developed in *M. musculus* – 1.24 mm/g and 13.34 mm<sup>2</sup>/g. In insectivorous shrews, the large intestine is very short and non-differentiated into segments. Its proportion in the length of the alimentary canal amounts only to 6.5%. The relative value of the length of the large intestine is between 1.34 mm/g of body weight (*S. araneus*) and 2.01 mm/g (*S. minutus*).

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### Introduction

The use of cellulose present in food is possible due to bacteria in the alimentary canal and demands special conditions, created in mammals by multi-chamber stomach or caecum (Dellow and Hume 1982, Barboza and Hume 1992, Osawa and Woodall 1992). Experiments on rats show that a plant diet causes lengthening of large intestine whilst a meat diet causes its shortening (Dorożyńska *et al.* 1971, Radzikowska 1981). In the experiments carried out on *Holochilus venezuelae* and *Zygodontomys microtinus*, given varied amounts of cellulose in food (25-45%), there was a direct relationship between the length growth of the caecum and the amount of cellulose in the diet (Dominiguez-Bello and Robinson 1991).

A majority of the morphometrical research on the alimentary canal presents only the lengths of parts of large intestine. To define the anatomical basis of

functioning of the large intestine as an organ of cellulose digestion, water absorption, and the formation and temporal storage of faecal mass, it is vital to know the areas of the mucosa in particular parts of the large intestine.

I carried out the study on the large intestine of two wild-living species of Insectivora (*Sorex minutus* and *Sorex araneus*); four wild-living Rodentia (*Sicista betulina*, *Clethrionomys glareolus*, *Microtus oeconomus*, *Apodemus flavicollis*); and two laboratory rodents (*Mus musculus* and *Cavia porcellus*). These species represent different trophic types. The pygmy shrew and root vole are relative monophages, having carnivorous (*Sorex minutus*) and herbivorous (*Microtus oeconomus*) diets, respectively. The other species eat animal food (*S. araneus*, *S. betulina*) and also eat seeds and fruit during blooming period. In the summertime, *A. flavicollis* and *C. glareolus* also feed on insects which make up 30–70% of the diet (Obrtel 1973, 1974, Pernetta 1976, Holišova and Obrtel 1980, Pucek 1981). With laboratory animals, the lack of seasonal changes of food composition, with relation to their diversity with a possibility to choose, is frequently more limited than in natural environment. In its natural habitat, *M. musculus* is omnivorous (predominant grass seeds) and *C. porcellus* is herbivorous (grasses, herbs). In laboratory *M. musculus* and *C. porcellus* were fed with standard forage – for rodents.

### Material and methods

The wild-living species (*S. minutus*, *S. araneus*, *S. betulina*, *C. glareolus*, *M. oeconomus*, and *A. flavicollis*) were captured between July and August (1989–1992) in the Borki Forests (53°N, 23°E, north-east of Poland), *Mus musculus* (albino form) and *Cavia porcellus* came from laboratory breeding. For each species, I studied the alimentary canals of ten adult males and ten adult females (non-pregnant and non-lactating).

The alimentary canals were fixed in 10% neutralised formalin for 3–7 days. After rinsing and measuring the lengths of the alimentary canal (from the esophagus to the anus), the large intestine was cut. In rodents the large intestine is divided into three parts, ie caecum, colon and rectum. The division of the large intestine was made following Snipes (1982). Then, the lengths of the subsequent parts of the large intestine were measured. With use of the drawing apparatus, a distinguished fragment was projected from under the magnifying reading glass onto a sheet of paper and thus drawn. The length obtained this way was measured with the curvature apparatus and, after considering linear magnifying (14 ×), the actual value of the part was calculated.

From the large intestine of shrews and from each part of the large intestine of rodents, I selected several millimeter-long sections at regular intervals (1.5 mm for shrews and 6.0 mm for rodents).

The sections were processed using a standard paraffin method. I cut the blocks transversely into slices of 5  $\mu$ m, which were then stained in Delafield's hematoxiline and eosin (HE) (Burck 1975). The sections were used to measure further (with magnification 250 × in shrews and 15 × in rodents) the external and internal circumferences of the consecutive slices. Multiplying average external circumference and internal one (the mean number of the series of measurements of consecutive slices) by the segment length, the external and internal areas of the large intestine were thus obtained.

The results of the measurements and calculations were then presented as mean numbers, giving standard average deviation. Significance of the differences was checked using Student's *t*-test, with  $p < 0.05$  as statistically significant.



## Results

### Anatomical structure of large intestine

The large intestine of *Sorex araneus* and *Sorex minutus* was non-differentiated (the lack of colon and caecum) and the shortest segment of the alimentary canal amounts to 6.5% of its length. But, in rodents the large intestine was very long and divided into the following parts (except in *S. betulina* where there was no colon): caecum, colon and rectum (Table 1)

The first part of the large intestine (caecum) in *M. musculus* and omnivorous species (*S. betulina*, *A. flavicollis*) reaches from  $28.8 \pm 2.13$  mm to  $47.1 \pm 9.19$  mm, which is 5–10% of total alimentary canal length. In herbivorous root vole, the length is of  $135.1 \pm 41.99$  mm (22% of total length of the alimentary canal). Similarly, the external and internal diameters of the caecum reach the highest sizes in the herbivorous species of rodents. The size of the external diameter ranged from  $4.9 \pm 0.47$  mm (*M. oeconomus*) to  $6.1 \pm 0.69$  mm (*C. glareolus*) and the smallest external diameter in the northern-birch mouse (feeding on mixed food) does not exceed 2.0 mm (Table 1).

The colon reached length from  $20.6 \pm 4.73$  mm (*M. musculus*) to  $174.9 \pm 21.71$  mm (*C. porcellus*), which is 4 and 6% respectively of the length of alimentary canal.

The terminal, longest part of the large intestine was the rectum. In the northern-birch mouse and in the house mouse, the length of the rectum slightly exceeded 60.0 mm (20 and 11% respectively of canals length), in the common bank vole and root vole the length was over 150.0 mm and it was longest in the guinea pig –  $616.7 \pm 125.37$  mm (25% of total canals length). Within the large intestine, the rectum had the smallest internal and external diameters (Table 1).

The large intestines length makes up between 20% (house mouse) to 53% (root vole) of the total length of the alimentary canal of rodents. Figs 1 and 2 present the relative value of the alimentary canal length (mm/g) and its internal area ( $\text{mm}^2/\text{g}$ ).

### Structure of mucosa and its sizes

In the large intestine of the studied species, a well-developed mucosa and submucosa created longitudinal folds. In each segment of the large intestine, both low and high folds (low folds are 0.5 of high folds) were distinguished. Their number and height differed in particular parts of the large intestine (Table 1).

The large intestine of the pygmy shrew had the largest number (6–9) of low folds and among rodents – in the caecum of the root vole (ca 8). The number of high folds was the largest in *Cavia porcellus* (12 – rectum) (Table 1). *Microtus oeconomus* represented a peculiarly-structured mucosa in the caecum and colon; here, besides low folds in caecum, there is a fold exceeding others in height by ten times ( $2429.4 \pm 646.78$  m) ( $p \leq 0.05$ ). The fold is slightly lower in colon ( $1868.2 \pm 286.94$  m). There are other three folds in the colon and they reach from 612.5 to 943.3 m. Low folds (4 of them) are from  $269.5 \pm 28.43$  to  $494.9 \pm 4.21$  m.

Table 1. The size of the large intestine and its component structures (arithmetical mean  $\pm$  SD) in various species of rodents and shrews. Ex - external surface area of the mucosa, In - internal surface area of the mucosa.

Species	Diameter			The size of the folds				The surface area of the mucosa		
	Length (mm)	Ex (mm)	In (mm)	Number		Height		Ex (mm <sup>2</sup> )	In (mm <sup>2</sup> )	In/Ex
				low	high	low	high			
<b>Insectivora</b>										
<i>Sorex minutus</i>	8.3 $\pm$ 1.15	1.3 $\pm$ 0.11	1.0 $\pm$ 0.13	6-9	3	145.7 $\pm$ 7.90	279.4 $\pm$ 19.08	33.5 $\pm$ 9.29	34.9 $\pm$ 6.29	1.04
<i>Sorex araneus</i>	14.3 $\pm$ 2.36	3.4 $\pm$ 0.69	2.7 $\pm$ 0.70	4	2	270.4 $\pm$ 51.18	654.2 $\pm$ 115.79	173.9 $\pm$ 12.43	136.4 $\pm$ 10.39	0.78
<b>Rodentia</b>										
<b>Large intestine</b>										
<b>Caecum</b>										
<i>Sicista betulina</i>	28.8 $\pm$ 2.13	1.8 $\pm$ 0.18	1.7 $\pm$ 0.08					166.1 $\pm$ 22.25	157.3 $\pm$ 20.20	0.95
<i>Clethrionomys glareolus</i>	93.9 $\pm$ 14.39	6.1 $\pm$ 0.69	5.4 $\pm$ 0.18	8	1	268.0 $\pm$ 34.48	2112.8 $\pm$ 164.84	1523.1 $\pm$ 353.47	1495.4 $\pm$ 565.53	0.98
<i>Microtus oeconomus</i>	135.1 $\pm$ 41.99	4.9 $\pm$ 0.47	4.7 $\pm$ 0.49		3	354.0 $\pm$ 18.0		2113.4 $\pm$ 556.38	2366.7 $\pm$ 325.45	1.12
<i>Apodemus flavicollis</i>	47.1 $\pm$ 9.19	3.4 $\pm$ 0.88	3.2 $\pm$ 0.98		1	447.7 $\pm$ 42.22	848.7 $\pm$ 32.93	519.7 $\pm$ 176.52	481.7 $\pm$ 127.89	0.93
<i>Mus musculus</i>	28.8 $\pm$ 6.06	3.8 $\pm$ 0.09	3.0 $\pm$ 0.25		8	450.0 $\pm$ 38.12		344.9 $\pm$ 78.16	309.5 $\pm$ 90.96	0.89
<i>Cavia porcellus</i>	462.8 $\pm$ 29.68	6.0 $\pm$ 0.38	5.6 $\pm$ 0.26					8139.0 $\pm$ 1095.09	7581.0 $\pm$ 990.55	0.93
<b>Colon</b>										
<i>Clethrionomys glareolus</i>	34.2 $\pm$ 4.96	5.4 $\pm$ 0.25	5.2 $\pm$ 0.11	4	3	368.5 $\pm$ 23.51	779.9 $\pm$ 110.33	124.1 $\pm$ 28.31	137.5 $\pm$ 36.68	1.11
<i>Microtus oeconomus</i>	29.5 $\pm$ 5.80	2.4 $\pm$ 0.11	1.8 $\pm$ 0.36		5	405.6 $\pm$ 41.39		224.6 $\pm$ 49.03	344.5 $\pm$ 90.18	1.53
<i>Apodemus flavicollis</i>	25.9 $\pm$ 2.33	2.8 $\pm$ 0.54	2.5 $\pm$ 0.58		2	544.8 $\pm$ 77.39	893.0 $\pm$ 24.03	233.0 $\pm$ 72.67	268.8 $\pm$ 83.48	1.15
<i>Mus musculus</i>	20.6 $\pm$ 4.73	3.4 $\pm$ 0.11	2.9 $\pm$ 0.17		6			233.8 $\pm$ 19.78	336.7 $\pm$ 57.35	1.44
<i>Cavia porcellus</i>	174.9 $\pm$ 21.71	2.8 $\pm$ 0.65	2.4 $\pm$ 0.81					905.6 $\pm$ 189.54	1295.0 $\pm$ 214.88	1.43
<b>Rectum</b>										
<i>Sicista betulina</i>	57.8 $\pm$ 4.34	1.2 $\pm$ 0.13	1.0 $\pm$ 0.15	5	6	143.2 $\pm$ 29.79	307.5 $\pm$ 15.49	216.5 $\pm$ 36.81	403.3 $\pm$ 71.85	1.86
<i>Clethrionomys glareolus</i>	150.4 $\pm$ 21.04	4.8 $\pm$ 0.36	4.2 $\pm$ 0.58	3	5	242.4 $\pm$ 7.40	508.7 $\pm$ 67.29	1046.6 $\pm$ 173.39	981.9 $\pm$ 261.93	0.94
<i>Microtus oeconomus</i>	152.1 $\pm$ 7.26	1.7 $\pm$ 0.35	4.0 $\pm$ 0.11	3	8	207.9 $\pm$ 7.16	385.8 $\pm$ 12.81	823.6 $\pm$ 215.99	1194.6 $\pm$ 273.73	1.45
<i>Apodemus flavicollis</i>	100.7 $\pm$ 11.42	2.2 $\pm$ 0.09	1.9 $\pm$ 0.04	2	3	478.7 $\pm$ 12.60	691.3 $\pm$ 76.43	667.1 $\pm$ 97.05	735.4 $\pm$ 28.44	1.10
<i>Mus musculus</i>	60.1 $\pm$ 5.03	2.8 $\pm$ 0.41	2.0 $\pm$ 0.42		12			539.3 $\pm$ 112.59	532.4 $\pm$ 77.54	0.99
<i>Cavia porcellus</i>	616.7 $\pm$ 125.37	2.2 $\pm$ 0.04	1.8 $\pm$ 0.16					5682.9 $\pm$ 258.71	7956.0 $\pm$ 439.30	1.40



Because of the poor development of the mucosa area in the large intestine, its structures (longitudinal folds) slightly extended the sizes of the internal area. The coefficient of the development of the mucosa, expressed through a ratio of external area to internal area, reached 1:0.78 in the insectivorous (common shrew) and 1:1.04 (pygmy shrew); being higher in rodents, it reached 1:1.47 (max in northern-birch mouse).

The internal area of the caecum reached considerably high sizes in the herbivorous rodents. The relative value ( $\text{mm}^2/\text{g}$  of body weight) in the internal

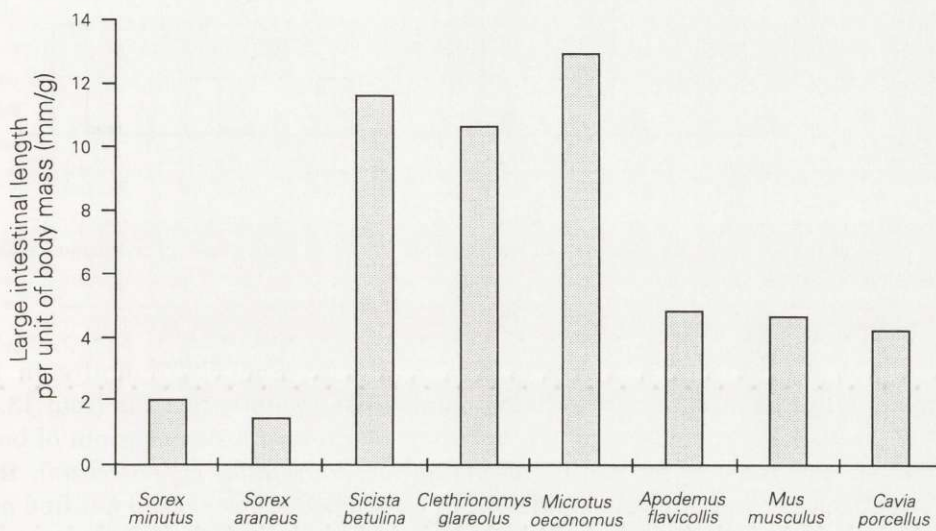


Fig. 1. Ratio of the large intestinal length (mm) to body mass (g) in various species of rodents and shrews.

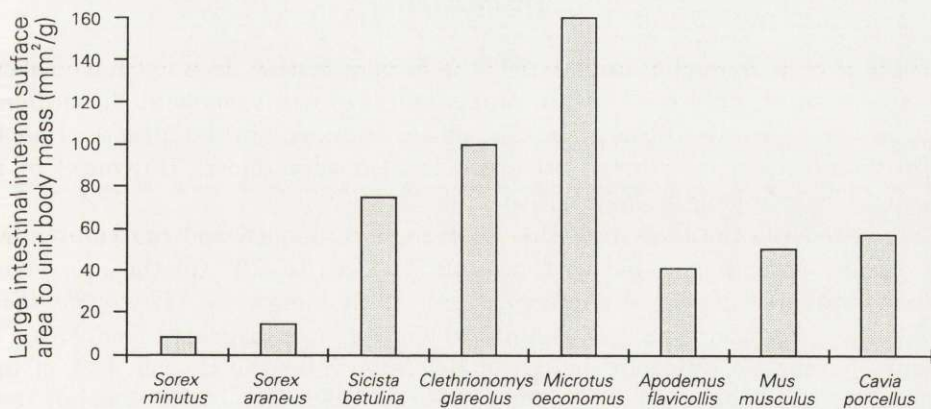


Fig. 2. Ratio of the large intestine internal surface area ( $\text{mm}^2$ ) to body mass (g) in various species of rodents and shrews.

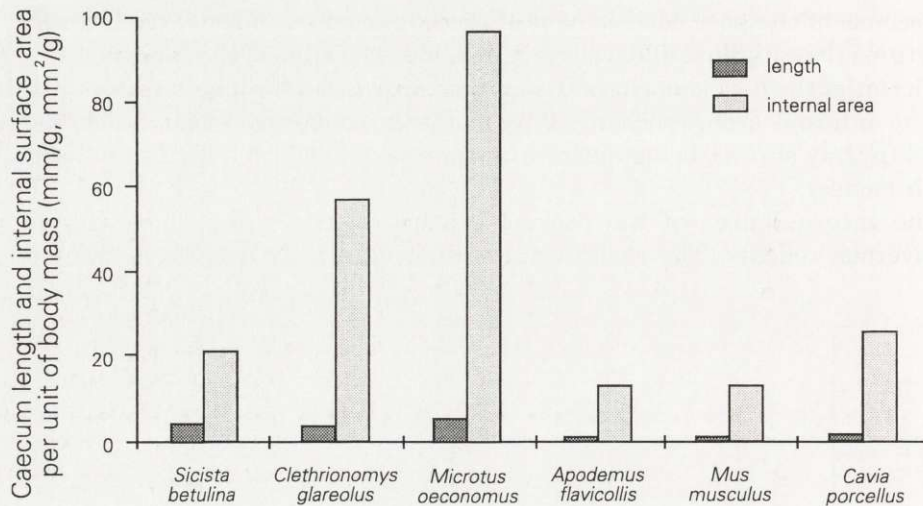


Fig. 3. Ratio of the caecum length (mm) and surface area (mm<sup>2</sup>) to body mass (g) in various species of rodents and shrews.

area of the caecum is 57.27 mm<sup>2</sup>/g in *C. glareolus* and 97.07 mm<sup>2</sup>/g in *M. oeconomus*. In the caecum of wild-living omnivorous rodents, there is from 13.49 mm<sup>2</sup> (*A. flavicollis*) to 21.06 mm<sup>2</sup> (*S. betulina*) of internal area per gram of body weight. In the rodents fed with granulates (*M. musculus*, *C. porcellus*), this coefficient reaches similar values (Fig. 3). In all studied species, I did not find any significant statistical differences either in the length or external and internal areas of the large intestine between males and females.

### Discussion

In the shrews living on animal diet, the large intestine does not have caecum and is very short, only 6.5% of the canals length. In this segment, formation of faecal pellets and water absorption take place. Similarly, in the insectivorous bat (*Tadarida nigeriae*), the large intestine is also very short, 7% (max) of the alimentary canals length (Okon 1977).

But, in rodents the large intestine is strongly developed and contributes from 20% (in the house mouse fed with granulated food) to 53% (in the root vole, a typical herbivore) of the alimentary canal. With kangaroos (*Thylogale thetis*, *Macropus eugenii* and *Macropus giganteus*) which live on hydrated food with a big amount of cellulose, the total length of the large intestine is over 43% of total length of the alimentary canal (Dellow and Hume 1982, Osawa and Woodall 1992). In the herbivorous root vole living on plant diet caecum is a very large part (43%) of the large intestine. In the South-American voles, *Holochilus venezuelae* and



*Zygodontomys microtinus*, Dominguez-Bello and Robinson (1991) showed directly a proportional relationship between the length of the caecum and the mass of given cellulose in the diet.

Plant food, unlike animal food, is not rich in calories and needs more time to be digested; access to it varies throughout the year in moderate climate and is usually very hydrated (green parts of plants). The herbivore show, therefore, the increased volume and area of the large intestine. In parts of the large intestine, the surface area of the mucosa is important in *C. glareolus* and *M. oeconomus* and reaches 57.27 mm<sup>2</sup>/g and 97.07 mm<sup>2</sup>/g respectively. Numerous high longitudinal folds affect the increase in the internal area of particular parts of the large intestine in the rodents. The presence of an extra fold in the root vole in the caecum and in the colon is connected with digesting cellulose. Taking into account the works of Bjorndal *et al.* (1990) on the phenomenon of cycotrophy in rodents and on the mechanisms called segregation of food in colon (Vorontsov 1967, Björnhag and Sjoblon 1977, Batzli and Cole 1979, Björnhag *et al.* 1994), this may be significant in absorbing cellulose. Through bacterial concentration and re-directing of food by the fold from colon to caecum, each portion of food undergoes fermentation and absorption at least twice.

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