(13). With human beings the difference in molecular weight between the fast one and the slow one is smaller (530,000 daltons and 540,000 daltons) (5).

The electrophoretic mobility in electrophoretic experimental conditions was higher for the fast ferritin than for the slow one (table I). These data for the fast ferritin and the slow one point out that the slow ferritin band is outstanding in adult male rats while the fast one is more abundant in females (14). This study was carried out in adult chickens.

The iron analysis showed the presence of 194Fe atoms per fast ferritin molecule as opposed to the 165 linked by slow molecule. These results agree with others (17) which emphasize the fact that acid ferritins (muscular and cardiac) have a low content, and that the fast one links this element more easily than the slow one (9).

The results of comparative amino acid analysis between the two types of muscle ferritin from chickens showed (table II) a general higher proportion of acid amino acid than the basic ones, not only for fast and slow ferritin in chicken muscle, but also for chicken and dove liver ferritin. This fact agrees with all other ferritin studied so far. In chicken muscle ferritin, although there is a double phenylalanine concentration in the slow component, the amount of histidine and methionine in the fast ferritin is double the amount in the slow one.

Tyrosine is the amino acid found in the lowest proportion, whose content is very low but similar in both ferritins.

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Resumen

Se estudia la existencia de dos ferritinas (rápida y lenta) en el músculo de pollo, aisladas mediante técnicas de fraccionamiento basadas en cambios de pH, fraccionamiento salino y térmico. La purificación se realiza por cromatografía en columna con Ultrogel AcA-34 y posterior ultracentrifugación a 100.000 *g* y la identificación, por electroforesis en gel de acrilamida. La caracterización de ambas ferritinas se lleva a cabo por medidas de su peso molecular, número de subunidades, análisis de amino ácidos y número de átomos de hierro unidos a la proteína, así como otros parámetros, carga eléctrica y movilidad electroforética.

Palabras clave: Hierro, Ferritina, Aves, Ferritina muscular de pollo.

References

1. Aurora, R. S., Lynch, E. C., Whitlej, C. E. and Alfred, C. P.: *Texas Rept. Biol. Med.*, **28**, 180-186, 1970.
2. Drysdale, J. W., Adelman, G. and Arosio, P.: *Hematol. Seminars*, 74, 71-88, 1977.
3. González del Barrio, M. S. P. and Martín Mateo, M. C.: *Comp. Biochem. Physiol.*, **76 B**, 567-568, 1983.
4. Linder, M. C. and Munro, H. N.: *Anal. Biochem.*, **48**, 226-278, 1972.
5. Linder, M. C., Nagel, G. M., Roboz, M. and Hugendorf, D. M.: *J. Biol. Chem.*, **256**, 9104-9110, 1981.
6. Linder-Horowith, M. C.: *Biochem. Biol. Acta*, **487**, 280-287, 1977.
7. Lowry, O. H., Rosebrough, N. J., Farr, A. L. and Randal, R. J.: *J. Biol. Chem.*, **193**, 265-275, 1951.
8. Martín Mateo, M. C., De No, C. and Sirgo, M.: *Comp. Biochem. Physiol.*, **89**, 1988. (In Press).
9. Munro, H. N. and Linder, M. C.: *Physiol. Rev.*, **58**, 317-396, 1978.
10. Nerenberg, S. T.: Electrophoresis. (A practical laboratory manual). Davies Philadelphia, 1968, pp. 223-236.
11. Ramsay, W. N. M. and Drysdale, J. W.: *Biochem. J.*, **95**, 282-288, 1965.
12. Santos Benito, F. F. and Martín Mateo, M. C.: *Comp. Biochem. Physiol.*, 74 **B**, 643-645, 1983.
13. Vulimiri, L. and Catsimpoolar, N.: *Biochem. Biophys. Acta*, 412, 148-156, 1975.
14. Vulimiri, L., Linder, M. C. and Munro, H. N.: *Biochem. Biophys. Acta*, **200**, 442-448, 1969.

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Adaptation of Electrolytes and Fluid Transport in Rat Small and Large Intestine After Distal Small Bowel Resection

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Na^+, Cl^- and water transport were studied in jejunum, caecum and colon after either 50 % or 80 % of small bowel resection (SBR). Four weeks after surgery, dry and wet weights, net absorption *in vivo* of sodium, chloride and water were determined. There was a significant intestinal growth after 50 % or 80 % SBR except for the colon which only showed increased tissue mass after 80 % SBR. Net transport was stimulated both, per organ and per unit mass. In the small intestine and caecum both organ growth and changes in cell function appear to be involved in the adaptive response, regardless the extent of the small intestine resected. In the colon, compensatory growth appear to contribute to the adaptive response only after 80 % SBR, whilst the transport function of the colonocytes seems to be stimulated after both types of SBR.

Key words: Intestinal resection, Electrolytes, Fluid, Transport

The long-term outcome of massive small bowel resection (SBR) depends in great part on the adaptive capacity of remnant intestine. Both, morphological and functional adaptations of the remainig small intestine have been extensively studied (5). However, few studies have examined the effect of distal SBR on the adaptive processes in the large bowel.

The aim on the current study was to investigate the effect of distal SBR on the transport capacity for sodium, chloride and water in the remaining small and large intestine (caecum and colon).

Materials and Methods

Wistar male albino rats weighing about 300 g were caged and allowed *ad libitum* access to tap water and commercial rat chow. The rats were randomly assigned to one of three groups: sham operation, 50 % and 80 % distal SBR. Operative

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details have been previously described (2).

Net water and electrolyte transport. — Four weeks after the operation, animals were starved overnight (with access to water only), anaesthetized with subcutaneous injection of sodium pentobarbital (4 mg/100 g body weight) and kept on a heated operating table at 36-38° C.

Following laparatomy, transport measurements were performed in the jejunum, caecum and colon. When the caecum was studied, ligatures were placed at the ileocecal and cecocolonic junction. From an opening cut into the lower caecum apex, contents were removed by repeated gentle washing with 37° C saline solution (0.9 % NaCl). Into the empty caecal sac physiological saline solution was then introduced in volumes chosen to be accomodated easily when adjusted to individual caecum size (2.5-6.0 ml in sham, 5.0-10.0 ml in resected rats). In the case of jejunum and colon, loops of about 10 cm length was rinsed with 0.9 % saline solution (37° C). When the effluent was translucent, jejunal and colonic loops were filled with 2 ml physiological saline solution at 37° C. The abdominal cavity was closed and the animal kept on the heated table for 1 h. At the end of the experiment (1 h) intestinal loops were removed, their fluid content collected, and their lengths and weights (wet and dry) recorded. Fluid transport was determined volumetrically as the difference between the known amount introduced and the final volume read to an accuracy of 0.1 ml (Sartorious 1207 MP2 analytical balance). Net transport of electrolytes was similarly determined from the difference between initial and final amounts, measuring sodium concentrations by flame photometry and chloride concentrations by titration. The transport data were calculated both, per gram of dry intestinal tissue (transport specific activity) and per centimeter of intestinal segment length or whole segment in the case of caecum (transport capacity).

Statistic. — Results are expressed as means ± S.E. of the mean. Significance has been assessed using the two tailed Student'st-test for unpaired variates.

Results

Observations in the whole animal. — Postoperative mortality was 10 % and 20 % after 50 % and 80 % SBR respectively. Deaths occurred within the first 5 postoperative days and were attributed to the surgery. Initial body weights in each group of animals were the same. At the time of the study, one month after the surgical operation, mean body weights were significantly lower in both 50 % and 80 % resected rats compared to sham rats (table I).

Mass parameters of intestinal tissue. — Caecal tissue dry and wet weights were significantly increased after both 50 % and 80 % SBR. Jejunal and colonic tissue mass (wet and dry), expressed as mg/cm, increased after 80 % SBR whilst 50 % SBR only increased jejunal tissue mass (table I). The tissue water content of the three intestinal segments studied (estimated from the dry and wet weights), wa not significantly modified after resection.

Intestinal transport. — Changes in intestinal transport will be described within two terms: transport-specific activity defined as transport per gram of dry tissue, and transport capacity defined as transport per centimeter of segment length for jejunum and colon, and transport per whole segment for the caecum. The transport capacity for sodium (fig. 1),

Table I. *Body weight (g) and intestinal tissue mass in sham and resected rats.*
Values are means ± S.E. for ten animals. w.w.: wet weight, d.w.: dry weight.

	SHAM		50 % RESECTED		80 % RESECTED	
Body weight						
At entry	326 ± 50		334 ± 60		324 ± 70	
At study	454 ± 60		405 ± 11^c		301 ± 80^a	
Intestinal tissue	w.w.	d.w.	w.w.	d.w.	w.w.	d.w.
Jejunum (mg/cm)	200 ± 10	39 ± 1	230 ± 10^d	43 ± 2^d	260 ± 20^d	47 ± 3^d
Caecum (g)	1.91 ± 0.12	0.28 ± 0.02	2.90 ± 0.29^b	0.39 ± 0.04^c	4.20 ± 0.32^a	0.48 ± 0.03^a
Colon (mg/cm)	300 ± 20	56 ± 4	340 ± 20	64 ± 4	360 ± 20^d	65 ± 3^d

a: $p < 0.001$, b: $p < 0.005$, c: $p < 0.01$, d: $p < 0.05$, as compared with sham rats.

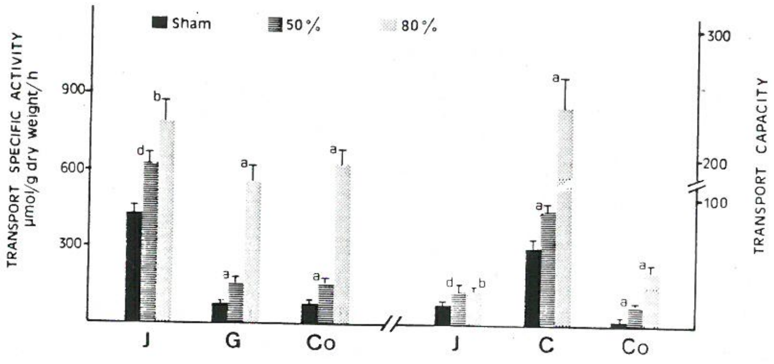

Fig. 1. *Net sodium transport across rat jejunum (J), caecum (C) and colon (Co) after 50 % and 80 % SBR.* Transport capacity: μml/h/cm in jejunum and colon or per total organ weight in caecun. Values are means ± S.E. of ten animals. a: $p < 0.01$, b: $p < 0.005$, c: $p < 0.01$, d: $p < 0.05$ as compared with sham rats.

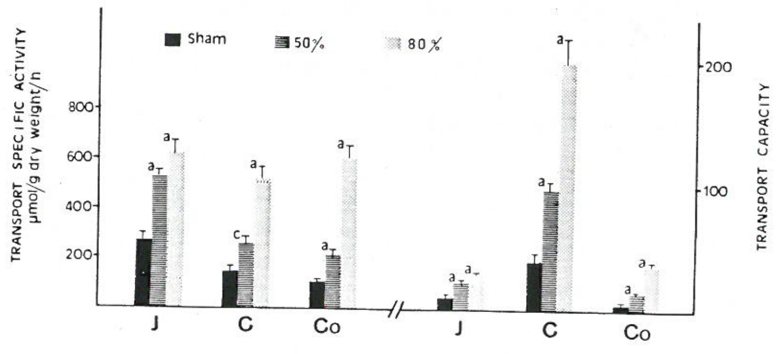

Fig. 2. *Net chloride transport across rat jejunum, caecum and colon after 50 % and 80 % SBR.* Values are means ± S.E. of ten animals (other details as in fig. 1).

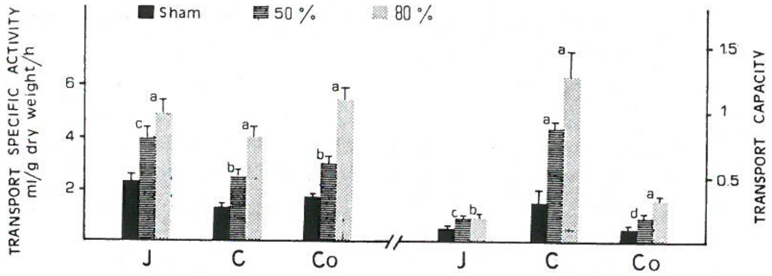

Fig. 3. *Net water transport across rat jejunum, caecum and colon after 50 % and 80 % SBR.* Values are means ± S.E. of ten animals. Transport capacity: ml/h/cm in jejunum and colon or per total organ weight in caecum. a: $p < 0.001$, b: $p < 0.005$, c: $p < 0.01$, d: $p < 0.05$ as compared with sham rats.

chloride (fig. 2) and water (fig. 3) was increased in the three intestinal segments after both 50 % and 80 % SBR. When the data were referred to unit dry weight (transport specific activity) resected animals also showed significantly higher transport in the three intestinal segments studied as compared to sham rats.

Discussion

In agreement with previous reports (5, 6), the current results show that when substantial parts of the small intestine are resected (80 %), the changes of mass parameters were much larger in the caecum than in the small intestine and colon. After 50 % SBR, significant increase in intestinal growth was limited to jejunum and caecum (table I). Light microscopy studies (7) revealed that both the mucosa and the underlying tissue took part in the growth response, and that the mucosal growth was due to hyperplasia.

Segment transport capacity is the essential functional measurement that determines long-term nutritional status of the animals after major SBR and can potentially be altered by two mechanisms: changes in mucosal mass, and changes in mucosal transport-specific activity. Concerning the electrolyte and water transport of the adapting mucosa, some discrepancies exist in the literature. PERRY (3) reported an increase in sodium and fluid transport in jejunum of resected rats. However, this (3) and other authors (4) failed to find adaptive increases in the transport capacity for fluid and electrolytes in rat colon. URBAN *et al.* (6) observed an increase in the transport capacity for sodium, chloride and water in rat colon, but not in the caecum, at four weeks after 70 % SBR, whilst other report (1) showed an increase in chloride and potassium transport in the cecum but not in the colon of resected rats. However, in both studies net transport was stimulated per organ, but not per unit mass, indicating that enlargement of the organ, but not changes in the cell function, was responsible for the observed increase in intestinal transport. The present results show that in the small intestine, caecum and colon, the transport capacity for sodium, chloride and water significantly increased after 50 % and 80 % SBR. This increase in transport capacity was not entirely due to the observed increase in the tissue mass, since reference to unit dry weight did not abolish the differences between groups. Furthermore, 50 % SBR increased colonic transport capacity for fluid and electrolytes without significant concomitant increase in intestinal growth. The results suggest that SBR, in addition to induce a compensatory growth, stimulated the transport function of the epithelial cells of the caecum, colon and remaining small intestine.

In conclusion, the current study shows that besides the small intestine, both the caecum and colon contribute to intestinal adaptation after 50 % and 80 % distal SBR, and that both, organ growth and changes in transport function of the epithelial cells appear to be involved in the adaptive response of the bowel to intestinal resection.

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Resumen

Se estudia el transporte de agua, Na^+ y Cl^- en el yeyuno, ciego y colon de ratas sometidas a una resección del 50 % y 80 % del intestino delgado distal. La absorción *in vivo* de agua, sodio y cloruro, y los pesos seco y húmedo de los segmentos intestinales estudiados, se determinan cuatro semanas después de la operación. Se comprueba que después de ambos tipos de resección aumenta significativamente la masa intestinal excepto en el colon, donde sólo aumenta tras la resección intestinal del 80 %. El transporte neto se estimula tanto por órgano como por unidad de masa. En el intestino delgado y ciego, la respuesta adaptativa parece ser debida a un aumento en la masa intestinal y a cambios en la función celular con independencia de la longitud del intestino delgado resecсionado. El crecimiento de la masa intestinal en el colon, parece contribuir a la respuesta adaptativa sólo tras la resección masiva (80 %), mientras el transporte de los colonocitos podría estimularse tras ambos tipos de resección.

Palabras clave: Resección intestinal, Electrolitos, Fluido, Transporte.

References

1. Loeschke, K., Fabritius, H. and Welter, H. F.: *Pflugers Arch.*, **406**, 323-327, 1986.
2. Murillo, M. L., Campos, M. S., Mataix, F. J and Varela, G.: *Rev. esp. Fisiol.*, **34**, 365-370, 1978.
3. Perry, M.: *Ann. R. Coll. Surg. Engl.*, **57**, 139-147, 1975.
4. Scarpello, J. H. B., Cary, B. A. and Sladen, G. E.: *Clin. Sci. Mol. Biol.*, **54**, 241-249, 1978.
5. Urban, E., Mochel, A. V., Weser, E.: In «Mechanism of intestinal adaptation» (Robinson, J. W. L., Dowling, R. H. and Riecken, E. O., eds.). MTP Press Ltd. Lancaster, (England), 1982, pp. 529-541.
6. Urban, E., Starr, P. E. and Michel, A. M.: *Dig. Dis. Sci.*, **28**, 265-272, 1983.
7. Vázquez, C. M., Molina, M. T. and Ilundain, A.: *Acta Microscopica*, **10**, 57-65, 1987.