Dietary polyamines are essential luminal growth factors for small intestinal and colonic mucosal growth and development

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Abstract

**Background**—Polyamines are essential for cell growth. Dietary and probably gut bacterial derived polyamines contribute significantly to the polyamine body pool.

**Aims**—To evaluate the influence of dietary, luminal polyamines on growth and development of different gastrointestinal organs in normally growing rats.

**Methods**—Male suckling Wistar rats were randomly allocated to four treatment groups: polyamine deficient diet (PDD); PDD plus antibiotics (neomycin 2 g/kg and metronidazole 34 mg/kg); PDD plus polyamine supplementation at normal concentrations; or normal standard laboratory chow. After a six month feeding period 7–10 animals/group were sacrificed.

**Results**—No differences in body weight gain, food consumption, or general behaviour could be observed between the four groups of animals. Feeding of PDD alone or PDD plus antibiotics resulted in a highly significant decrease in organ weight, protein content, and DNA content in small intestinal and colonic mucosa whereas no alterations were found in the liver.

**Conclusions**—Long term feeding of polyamine deficient diets resulted in a significant hypoplasia of small intestinal and colonic mucosa whereas no alterations were found in the liver. Dietary, luminal polyamines are important local factors for growth and the development of small intestinal and colonic mucosa. Dietary, luminal polyamines are important local factors for growth and development of various gastrointestinal organ systems in normally growing rats.

Because of its high proliferation rate, intestinal and colonic mucosa has a special demand for polyamines. Uptake of extracellular polyamines via luminal or basolateral membrane either by distinct polyamine carriers or passive diffusion was found to be an important regulatory mechanism of polyamine metabolism during small intestinal and colonic adaptation. Oral administration of spermine or spermidine was able to induce precocious morphological and functional maturation of the small bowel and accelerated early intestinal development. On the other hand, deprivation of gastrointestinal polyamines by feeding polyamine deficient diets and reducing luminal polyamine producing bacteria by oral antibiotics caused a significant reduction in solid tumour proliferation and confirmed the relevance of luminal polyamines for malignant growth.

While the importance of luminal gastrointestinal polyamines for adaptive and malignant growth is well documented, little is known about their function in normal, physiological organ growth. The present study was designed to evaluate the long term effects of dietary and gut bacterial derived polyamines on growth and development of various gastrointestinal organ systems in normally growing rats.

**Materials and methods**

**CHEMICALS**

The following substances were purchased from Sigma Chemical Co. (St Louis, Missouri, USA): α-phthalaldehyde, 1,7-diaminoheptane and polyamine standards, Brij 35, bovine serum albumin, calf thymus DNA, sucrose, Tris buffer, dithiothreitol, pyridoxal phosphate, hyamine hydroxide, neomycin, metronidazole, and ammonium formate. Acetonitrile, glycerol (87%), disodium phosphate, and phenylmethylsulphonyl fluoride were from Merck (Darmstadt, Germany). DL-[1-14C] ornithine, S-adenosyl-L-carnobxyl-15C methionine, 1-14C-acetyl CoA, and methyl-13H-thymidine triphosphate were used.

**Abbreviations used in this paper:** AB, antibiotics; ODC, ornithine decarboxylase; PA, polyamines; PDD, polyamine deficient diet; SAM-DC, S-adenosylmethionine decarboxylase; SAT, spermidine/spermine N'-acetyltransferase.
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DIETS
Standard laboratory chow as well as the different special diets were obtained from Altromin (Lage/Lippe, Germany). Polyamine deficient diet (PDD), polyamine deficient diet plus antibiotics (neomycin 2 g/kg and metronidazole 34 mg/kg) (PDD + AB), as well as polyamine deficient diet plus normal, physiological supplementation with polyamines (putrescine 80 mg/kg, spermidine 300 mg/kg, spermine 100 mg/kg) (PDD + PA) were identically prepared as previously published by Seiler and colleagues and Sarhan et al. The polyamine deficient diets used in this study were fully balanced, well tolerated animal diets. HPLC analysis revealed a putrescine, cadaverine, and spermine content below the detection limit of the method; spermidine content was less than 98% compared with standard laboratory chow (560 nmol/g).

DIETS

Animal behaviour, and stool characteristics. After a six month feeding period 7–10 animals/group were killed and the following parameters were analysed in small intestine, colon, and liver: organ wet weight; single blinded, detailed histological analysis of all organs by a skilled pathologist (DH); protein and DNA content; DNA polymerase activity; polyamine concentrations; and activities of ornithine decarboxylase (ODC), S-adenosylmethionine decarboxylase (SAM-DC), and spermidine/spermine N'-acetyltransferase (SAT). For statistical analysis the PDD + PA fed animals are regarded as the control group.

EXPERIMENTAL DESIGN
Male suckling Wistar rats were randomly allocated directly after weaning into one of four different treatment groups: (1) polyamine deficient diet (PDD); (2) polyamine deficient diet plus antibiotics (PDD + AB); (3) polyamine deficient diet plus supplementation with putrescine, spermidine, and spermine at physiological concentrations (PDD + PA); and (4) normal standard laboratory chow. Once a week the following parameters were registered: body weight, water and food consumption, animal behaviour, and stool characteristics. After a six month feeding period 7–10 animals/group were killed and the following parameters were analysed in small intestine, colon, and liver: organ wet weight; single blinded, detailed histological analysis of all organs by a skilled pathologist (DH); protein and DNA content; DNA polymerase activity; polyamine concentrations; and activities of ornithine decarboxylase (ODC), S-adenosylmethionine decarboxylase (SAM-DC), and spermidine/spermine N'-acetyltransferase (SAT). For statistical analysis the PDD + PA fed animals are regarded as the control group.

ANALYTICAL PROCEDURE
Homogenisation
The whole small intestine, colon, and liver were removed and homogenised 1:5 on ice, firstly in a buffer solution consisting of 10 mM Tris buffer (pH 7.9), 25 mM KCl, 5 mM MgCl 2, 0.25 M sucrose, 5 mM dithiothreitol, and 1 mM phenylmethylsulphonyl fluoride with a Potter S homogeniser at 1000 rpm (Braun, Melsungen, Germany; 10 up and down strokes) and then with a Dounce glass/glass homogeniser (Kontes Glass, Vineland, New Jersey, USA; 15 up and down strokes). Aliquots were taken and stored at −20°C until required for DNA protein and polyamine analyses. The remainder of the raw homogenate was centrifuged at 1000 g for 10 minutes; the supernatant was removed and ultracentrifuged at 110 000 g (2°C) for 50 minutes. Aliquots of the resulting cytosol fraction were taken for the determination of ODC, SAM-DC, and DNA polymerase and frozen at −20°C until analysis. ODC and SAM-DC activities were analysed the same day.

Ornithine decarboxylase
ODC activity was calculated by measuring the picomoles of CO₂ liberated from the 1-14C-adenosyl-L-carboxyl-14C-methionine (2.07 GBq/mmol) plus spermidine. SAT activity was measured according to the method described by Matsui and colleagues. Enzyme activity was expressed as picomoles 14CO₂/30 min/mg DNA.

S-adenosylmethionine decarboxylase
SAM-DC activity was calculated by measuring the picomoles of CO₂ liberated from the substrate S-adenosyl-L-carboxyl-14C-methionine (2.07 GBq/mmol) according to the method of Pegg and Pössö. Enzyme activity was expressed as picomoles 14CO₂/30 min/mg DNA.

Spermidine/spermine N'-acetyltransferase
SAT activity was measured according to the method described by Matsui and colleagues by determining the formation rate of 1-C-labelled N'-acetylpermidine from 1-C-acetyl CoA (2.07 GBq/mmol) plus spermidine. SAT activity was calculated as picomoles N'-acetylpermidine/min/mg DNA.

DNA polymerase
DNA polymerase activity was calculated as picomoles methyl-1H-thymidine triphosphate (1.78 TBq/nmol) incorporated/30 min/mg DNA as described in detail by Haarstad et al. Methyl-1H-thymidine 5-triphosphate (20 pmol) and 25 µg activated calf thymus DNA were used as substrate. All assays were run in triplicate.

Polymamines
For polyamine separation an ion pairing reversed phase HPLC (Merck-Hitachi, Tokyo, Japan) method followed by postcolumn derivatisation with o-phthalaldehyde and consecutive fluorescence detection (F1000 fluorescence photometer) was used as previously published in detail. In contrast to the previously published method, the final dilution of pancreatic tissue for polyamine analysis was 1/10. Putrescine, spermidine, and spermine concentrations were calculated as nmol/mg DNA.
DNA assay
DNA content was measured using the fluorescent dye H-33258 according to the method of Labarca and Paigen. Calf thymus DNA was used as standard. DNA content was expressed as milligrams per total organ.

Protein
Protein content was determined according to the method of Bradford using bovine serum albumin as standard. Protein content was expressed as milligrams per total organ.

Statistics
Results were calculated as mean (SD) values. The between group statistical significances were evaluated by Student’s t test for unpaired values adapted for multivariate comparisons according to Holm.

Results
Feeding of the PDD reduced alimentary polyamine intake by 98% (0.20 µmol/day). Average daily polyamine intake in PDD plus PA fed animals (18.8 µmol/day) was similar to those fed with standard laboratory chow (15.3 µmol/day).

Animal Development
Food consumption and course of body weight during the 26 week feeding period revealed no significant differences between the four different treatment groups. Furthermore, no alterations in general animal behaviour or stool characteristics were observed during the half year feeding period. Long term feeding of all diets was well tolerated by the animals.

Histological Observations
Tissue samples of small intestinal and colonic mucosa as well as the liver were taken from all animals after the 26 week feeding period for single blinded histological examination by a skilled pathologist. Apart from a slight hypotrophic appearance of small intestinal and colonic mucosa in PDD and PDD + AB fed rats no significant histopathological changes, and particularly no inflammation or necrosis, were observed in the organs of any diet fed group compared with standard laboratory chow fed controls.

Trophic Parameters
Feeding of PDD + AB resulted in a significant (p<0.005) decrease in wet organ weight in small intestine and colon, while feeding of PDD significantly (p<0.01) decreased small intestinal mucosal weight (fig 1). Protein content of colonic mucosa and liver was not significantly different in the four treatment groups, but was significantly (p<0.01) decreased in small intestinal mucosa of PDD fed animals compared with PDD + PA fed controls (fig 2). Feeding of PDD or PDD + AB resulted in a significant decrease in DNA content in small intestinal (p<0.01) and colonic (p<0.005) mucosa, while DNA content was not altered in the liver in any treatment group (fig 3). In the liver no significant alterations were found in any of the different treatment groups (figs 1, 2, and 3). DNA polymerase activity was not significantly altered in any of the three organs of the animals fed with the different diets (data not shown).

Polyamine Metabolism
No significant changes in the activities of ODC, SAM-DC, or SAT, or concentrations of putrescine, spermidine, and spermine (data not shown) were observed in small intestinal mucosa, colonic mucosa, and liver between any of the four different treatment groups.
Dietary polyamines are essential for intestinal growth

Dietary polyamines are essential for intestinal growth and development, and are involved in various physiological and pathophysiological processes, including cell proliferation, differentiation, and regeneration. Dietary polyamines, such as ornithine, putrescine, cadaverine, and spermidine, are produced by the intestinal microbiota and absorbed into the bloodstream, where they can be used for cell proliferation and repair. These polyamines play a critical role in the maintenance of the intestinal epithelium, and their deficiency can lead to various adverse effects, including hypoplasia of the small intestine and colonic mucosa.

The diets used in the present study were identical to those used in previous studies, which showed that feeding of polyamine-deficient diets resulted in a significant hypoplasia of small intestinal and colonic mucosa. The present study confirmed these findings and revealed that dietary polyamines are important local growth factors for the nutrition and development of normally growing animals. The diets used in the present study were prepared identically to those used in previous studies, and were fed to rats for up to six months.

In conclusion, long-term feeding of polyamine-deficient diets resulted in a significant hypoplasia of small intestinal and colonic mucosa, irrespective of whether there was intracellular compensation of polyamine deficiency. The local mechanisms, however, are not yet known.

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