$n = 4$) were regurgitated with food in 1 percent (15 of 1709) of the fork-tailed storm-petrel samples; one bird regurgitated 12 particles. Sooty storm-petrels that forage in major tanker lanes near the Hawaiian Islands frequently ingest plastic; 6 of the 14 collected samples (43 percent) contained plastic. However, no samples ($n = 101$) from leach's storm-petrels contained plastic.

These results indicate that Procellariiformes can serve as effective monitors of marine environmental quality. From chemical analysis of gut samples, levels of oil pollution can be measured and compared between different geographical areas, and degradation of water quality within a particular region could be tracked. For example, plastics detected in gull and tern pellets on the eastern coast of the United States were eventually traced to several industrial sources (*13*). Because pollution from petroleum, plastics, and other contaminants is likely to be patchy and difficult or costly to sample directly, use of seabirds to monitor oceanic water quality and environmental change could contribute to protecting our marine resources.

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Retinal Dystrophy: Development Retarded by Galactose Feeding in Spontaneously Hypertensive Rats

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Retinal photoreceptor cell dystrophies have been widely observed in humans and in animals, but pathogenetic mechanisms are known in only a few such disorders, and successful therapeutic intervention has been reported in fewer still. Spontaneously hypertensive albino rats develop a retinal photoreceptor cell dystrophy with onset late in the first year or early in the second year of life. Between 60 and 70 percent of the animals are affected. A substantial reduction in the prevalence and severity of the dystrophy occurred in such animals whose diet contained 30 percent (by weight) D-galactose. Neither an inhibitor of the enzyme aldose reductase, present in the diet, nor diabetes mellitus, induced by streptozotocin, had any statistically significant influence on the dystrophy. Ambient light and systolic blood pressure levels also did not seem to influence the course of the disorder. The mechanism by which galactose exerts its effect is unknown, but a mutant enzyme with an elevated Michaelis constant (K_m) for galactose is plausible.

GENETICALLY DETERMINED RETINAL dystrophies have been described frequently in humans and in several animal species (*1*). In only a few cases, however, do we have sufficient anatomic or biochemical information to propose a hypothesis for the cause of the disorder. In the Royal College of Surgeons (RCS) rat strain, initial anatomical findings include an elongation of the outer segments of the retinal photoreceptor cells (*2*) due to a failure of the retinal pigment epithelial (RPE) cells to phagocytose the distal tips of the outer segments (*3*). Ultimately, the photoreceptors degenerate; complete degeneration and disorganization of the entire retina follows. In a study of tetraparental chimeras, Mullen and LaVail (*4*) demonstrated that the defect resides in the RPE cells and not in the photoreceptors. A specific biochemical defect has been demonstrated in the photoreceptor cells of C_3H mice and of Irish setter dogs with a hereditary rod-cone dysplasia (*5*). In these animals, deficient activity of cyclic guanosine monophosphate (cGMP) phosphodiesterase in the retinal outer segment permits large and eventually toxic (*6*) concentrations of cGMP to accumulate in the photoreceptor cells. In a rare human disorder, gyrate atrophy of the choroid and retina, absence or defective functioning of the enzyme ornithine aminotransferase leads to an accumulation of the amino acid ornithine, presumably resulting in retinal and choroidal degeneration (*7*). This is the only genetic retinal dystrophy for which claims have been made of effective dietary treatments, including diets low in protein and in the basic amino acid arginine (*8*), or, in some cases, dietary supplementation with large doses of pyridoxal phosphate (*9*), an essential cofactor for the defective enzyme.

We report here the dietary modulation of another retinal dystrophy (*10*) in the spontaneously hypertensive (SHR) strain of albino rats (*11*). A photoreceptor dystrophy was initially described in SHR rats by Mizuno *et*

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al. (*12*), and later in more detail by von Sallmann and Grimes (*13*), who reported its occurrence in 8 of 13 (62 percent) animals between 10 and 15 months of age. The animals described here were part of a larger study of SHR and Wistar-Kyoto (WKy) rats designed to evaluate ways of producing a vascular retinopathy resembling that seen in diabetes mellitus in humans. The effects of galactose feeding and aldose reductase inhibition on the thickness of the retinal capillary basement membrane in these animals have been described (*14*). The female SHR rats entered the study weighing approximately 100 g roughly 6 weeks after birth. They were maintained for between 10 and 21 months (all of the animals fed galactose were maintained for at least 15 months). All experimental groups received the Ralston Purina test diet, with modifications as follows: (i) 14 galactosemic animals were fed the test diet, in which the major carbohydrate source (dextrin) was replaced to 30 percent of the total weight of the diet by D-galactose. (ii) Eight of these animals also received the aldose reductase inhibitor Sorbinil (*d*-6 fluorospiro [chroman-4,4′-imidazoline]-2′,5′-dione; Pfizer) at a dose of 250 mg per kilogram of diet mixed in the pelleted test diet. Thus, the galactosemic animals received precisely the same diet as the nongalactosemic ones, save for their carbohydrate intake. (iii) The 32 nongalactosemic animals received the standard test diet, save that ten of these (seven diabetic and three nondiabetic) also received Sorbinil at the same dose as above. Diabetes was produced in 23 nongalactosemic animals by intraperitoneal injection of streptozotocin, 6.5 mg per 100 g of body weight, dissolved in normal saline. Eight of the diabetic animals subsequently received insulin [2 units of neutral protein Hagedorn (NPH), 1 unit regular per 100 g of weight] daily by subcutaneous injection. All animals received food and water ad libitum and were housed in stainless steel cages in racks in a room maintained at 23° ± 2°C on a cycle of 12 hours light, 12 hours dark. Ceiling-mounted fluorescent fixtures produced a luminance of 2.0 footcandles (21.42 lux) within the cages, with no measurable variation from front to back of individual cages, in cages at different heights within the racks, or in cages throughout the room. Mean systolic blood pressure, measured with a tail cuff sphygmomanometer within 1 month before death was 151 ± 16 (SEM) mmHg, with no significant variation among the different experimental groups.

Methods of euthanasia and of fixing and embedding posterior segments of the globes have been described (*14*). Five to ten Epon blocks were prepared from the posterior segment of each eye, within 2 mm of the optic nerve. These blocks were assigned random code numbers so that the animal of origin could not be identified by the reader. Sections 1 μm thick were cut from each block, mounted on glass slides, and stained with methylene blue–azure II. Sections were evaluated by a single reader. They were graded "normal" if all retinal structures were intact and showed no abnormality; "mild dystrophy" if partial loss of photoreceptor inner and outer segments and thinning of the outer nuclear layer to no less than a uniform thickness of one row of nuclei were observed; and "severe dystrophy" if the inner and outer segments were extensively lost and the outer nuclear layer was absent in patches, or completely, or if more severe retinal abnormality was observed (Fig. 1) (*15*). We graded eyes by the block showing the most extensive changes. We did not examine the peripheral retinas of our animals. Von Sallmann and Grimes (*13*) reported that the peripheral retinas of some of their SHR animals remained normal while the posterior retinas showed extensive changes, but they did not observe the reverse distribution.

Overall, 24 of 46 animals (52 percent) had dystrophic retinas, of which 14 (30 percent) were graded as "severe" and 10 (22 percent) as "mild." Of the nongalactosemic animals, 20 of 32 (63 percent) showed evidence of dystrophy, a figure almost identical to that reported by von Sallmann and Grimes (*13*). The retinal dystrophy was less prevalent in the galactosemic animals, with only 4 of 14 rats (29 percent) affected ($\chi^2 = 4.49$, $P = 0.034$; continuity-corrected $\chi^2 = 3.24$, $P = 0.072$; Fisher's exact test, two-tailed, $P = 0.071$) (*16*). Only one (7 percent) of the 14 galactosemic animals was severely dystrophic, by comparison with 13 (41 percent) of the controls. This difference was statistically significant ($\chi^2 = 5.16$; $P = 0.023$) (Fisher's exact test, $P = 0.041$, two-tailed), while the continuity-corrected χ^2 was 3.70 ($P = 0.055$).

No other experimental variable seemed to influence the prevalence and severity of the dystrophy (Table 1). The presence or absence of streptozotocin-induced diabetes had no statistically significant effect, nor did the use of Sorbinil in the diet. The presence of diabetes in the nongalactosemic animals seemed to exert a mild (though statistically nonsignificant) protective effect, and nongalactosemic animals fed Sorbinil had a mod-

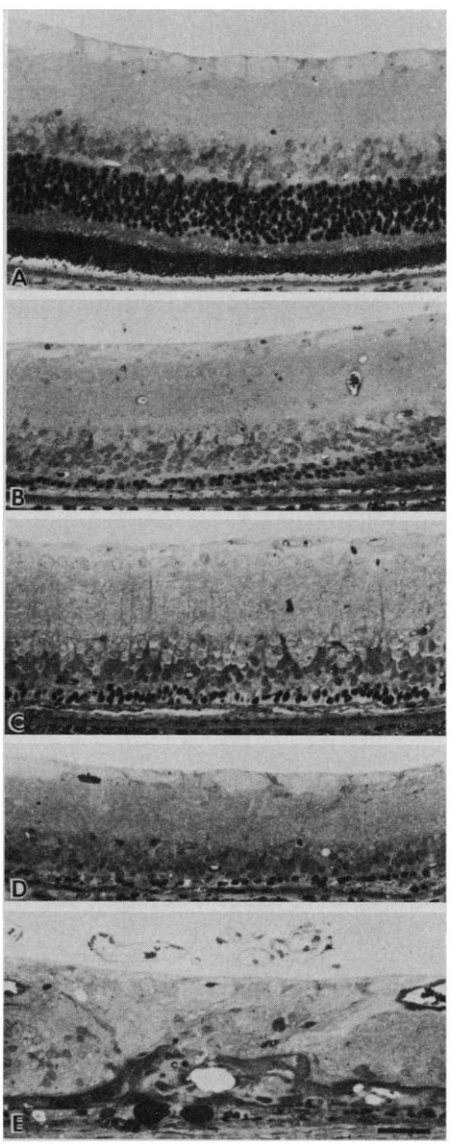

Fig. 1. Dystrophic changes in the retinas of SHR rats. (A) Normal retina. All neural layers are present and of uniform thickness, and the retinal pigment epithelium is intact. The photoreceptor outer segments and the retinal pigment epithelium are artifactually separated. (B) Mild dystrophy. The photoreceptor inner and outer segments have atrophied segmentally, and the outer nuclear layer (layer of photoreceptor cell nuclei) is variably thinned. The inner neuronal layers and retinal pigment epithelium appear normal. (C) Mild dystrophy. The photoreceptor inner and outer segments are absent, and an amorphous mass of degenerated photoreceptor material remains. The outer nuclear layer is diminished in most areas to only one row of nuclei. The inner neural layers are intact, and the pigment epithelium appears normal. (D) Severe dystrophy. The outer nuclear layer is often missing and otherwise reduced to only one row of nuclei. Portions of the retinal pigment epithelium show cytoplasmic vacuolization, and some pigment epithelial nuclei are pyknotic. The inner neural layers of the retina appear normal. (E) Severe dystrophy. All retinal layers are disorganized and neuronal cell nuclei are lost. The retinal pigment epithelium has proliferated in foci within the neural retina, and capillary profiles are dilated within the pigment epithelium. New vessels have proliferated from the retinal circulation into the vitreous cavity at the top of the micrograph. The calibration bar (lower right) represents 40 μm.

Table 1. Presence and severity of photoreceptor dystrophy in groupings of spontaneously hypertensive rats. The 46 animals are grouped in four ways. Since animals entered the experiment at 6 weeks (1.5 months) of age, ages are listed, arbitrarily, as the next integral month; that is, rats that were maintained for 21 months were listed under 23, not 22.5, months of age.

Grouping	Normal	Dystrophic		Total animals
		Mild	Severe	
	Effect of galactose			
Galactose	10	3	1	14
No galactose	12	7	13	32
	Effect of diabetes			
Diabetic	10	6	7	23
Nondiabetic	12	4	7	23
Nondiabetic, no galactose	2	1	6	9
	Effect of Sorbinil			
Sorbinil	9	2	7	18
No Sorbinil	13	8	7	28
Sorbinil, no galactose	4	0	6	10
No Sorbinil, no galactose	8	7	7	22
	Effect of age			
Age (months)				
11	3	0	0	3
12	0	0	0	0
13	0	0	1	1
14	3	0	0	3
15	0	4	3	7
16	5	4	3	12
17	3	1	3	7
18	4	0	4	8
19	1	0	0	1
20	0	0	0	0
21	0	0	0	0
22	0	0	0	0
23	3	1	0	4

estly greater, but also statistically nonsignificant, prevalence of severe dystrophy.

An influence of age on the prevalence of the dystrophy was not evident in our data (Table 1), nor in that of von Sallmann and Grimes (*13*). Their youngest affected animals were 10 months old (*13*), but studies of the eyes of younger SHR rats have not been described, and details of the onset and natural history of the disorder are lacking. A modest increase in severity of the disorder may be present in our 17- and 18-month rats by comparison with younger animals. All of the four oldest animals examined (at 23 months of age) were galactosemic. Only one of these had mild dystrophy, and the reduction in prevalence of the dystrophy in these older, galactosemic rats by comparison with the 15- to 18-month-old animals provides additional evidence for the protective effect of dietary galactose.

Although ambient light can cause a photoreceptor degeneration in the albino rat (*17*), it does not seem to have been a causal factor in our experiments. Light levels in the cages where the animals were housed were low and varied negligibly from cage to cage. Systolic blood pressures in galactosemic SHR rats were comparable to those of the other experimental groups. The data thus show no influence of systolic blood pressure on retinal dystrophy.

An explanation for our observations is speculative. SHR rats may have a defective enzyme, with an abnormally high K_m for D-galactose, whose normal function is to galactosylate critical plasma membrane proteins on the photoreceptor outer segments or retinal pigment epithelial cells. Alternatively, an enzyme that inserts galactose into glycosaminoglycans of the extracellular matrix between the photoreceptors and retinal pigment epithelial cells could be defective. Altered synthesis of a critical macromolecule would result in eventual expression of a retinal dystrophy. By supplying an excess of the substrate, a high-galactose diet could at least partially correct the defect. Although the biochemical basis for most of the retinal dystrophies of humans and animals is unknown, the demonstration here that a second such disorder can be modified by diet suggests that similar nutritional approaches may prove to be of more general benefit.

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10. We use the term "dystrophy" to emphasize the genetic component of the etiology of this disorder as well as that its course can be modified (as we demonstrate here) by altering the diet, rather than by altering the physical environment, for example, by changing the ambient light ["Dystrophy: Any disorder arising from defective or faulty nutrition," *Dorland's Illustrated Medical Dictionary* (Saunders, Philadelphia, ed. 25, 1974), p. 488]. That the disorder has its morphological onset relatively late in life and may have an environmental component to its etiology (since fewer than 100 percent of the animals at risk are affected) might also make the term "degeneration" appropriate. In practice, the terms are often used interchangeably (1).
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