Relative mole percentages of the phospholipid classes were not detectably different between groups. However, there was a trend toward positive correlation between the fatty acid precursors of the dietary supplements and the fatty acid composition of the phospholipid classes of the ROS membranes. With only 20 eyes for assay for each dietary group, we estimate an uncertainty of 5 percent for major fatty acid components of rat ROS, and hence it appears that the ERG achieved a steady state when no more than 5 percent of the polyunsaturated compounds were replaced in ROS membranes [also see (*14*)]. Inasmuch as the photocurrents are probably controlled by plasma membranes (*15*), it is interesting that ROS plasma membranes contribute no more than 5 percent to the total of rat ROS membranes. In addition, ROS plasma membranes apparently are renewed in a relatively brief time interval in which only a small percentage of total ROS membranes are renewed (*16*). These considerations suggest that perhaps the observed electrical alterations are associated with fatty acid substitutions in the plasma membrane, but our ERG measures are powerless to discriminate between electrical contributions from specific membrane systems such as plasma membranes, disc membranes, and mitochondrial membranes.

The ERG is an external field parameter which results from the currents generated by cells of the retina in response to illumination. As a consequence ERG alterations may arise from either or both of the following: (i) from alterations in the currents generated by retinal cells; (ii) from alterations in the passive impedance characteristics of the external field, where the external field includes extraretinal tissues of the eye such as the lens and aqueous and vitreous humors. However, the latter possibility seems extremely unlikely here because of the following considerations. If there were differential impedance changes in the extraretinal tissues of fat-free and supplemented animals, the changes were only resistive changes in the regions of the frequency domain occupied by the ERG response (*17*). Yet as a purely resistive attenuator the extraretinal tissue would modify all components of the ERG by the same percentage; that is, the ratio of a-wave to b-wave (a/b) would remain constant if the fatty acid substitutions only produced passive resistive changes in extraretinal tissue. This result was not observed. On a percentage basis, the a-wave was altered more than the b-wave, and the (a/b) ratios were different for different dietary groups (see Fig. 1). Equally compelling are the observations that (i) the a-wave amplitude continued to change as a function of time on a fat-deprived diet when the b-wave had achieved a steady-state value, and (ii) the rate constants for the a-wave and b-wave differed by several days (*11*). In summary, the b-wave provides an internal control against the possibility that these a-wave alterations were simply the result of passive impedance changes in extraretinal tissues of the eye.

The a-wave of the ERG seems to be primarily a response function of the photoreceptor cells of the retina, while the b-wave appears to arise from the response of other cells in the retina (*18*). With the b-wave as an internal control, we conclude from the a-wave data presented here that the electrical response of photoreceptor cell membranes is a selective function of $\omega 3$ and $\omega 6$ fatty acids.

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12. Fat-free diet was supplied by Nutritional Biochemicals. This diet contained traces of fatty acids associated with supplements of fat-soluble vitamins A, E, and K (see Table 1). All purified ethyl esters of fatty acids were supplied by NuCheck Prep (Elysian, Minn. 56028).
13. Although Fig. 1 shows only relative response amplitudes for 20-msec flashes at one value of stimulus flux (700 microwatts), relative ERG amplitudes were similar to those of Fig. 1 over the entire flux range from threshold to saturation in intervals of 0.5 log unit.
14. If data between 14-week-old adults are comparable to data on 3-week-old weanlings, approximately a 4 percent reduction in 22 : $6\omega 3$ would be expected after 40 days of fatty acid deprivation. This estimate is based on a linear extrapolation of an 8 percent change in 22 : $6\omega 3$, which was observed when 3-week-old weanlings were placed on a fat-free diet for 70 days (*7*).
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19. Supported by NSF grant GB-33499 to R.M.B., the Retina Research Foundation of Houston, NIH grants EY00244 and EY00871 to R.E.A. We appreciate discussion with S. F. Basinger, M. L. J. Crawford, D. J. Landis, and M. B. Maude.
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Parasite Reproductive Strategy and Evolution of Castration of Hosts by Parasites

Abstract. *A modification of the Euler equation is used to describe a simple parasite life history in which survival decreases with age at a rate determined by mortality of the parasitized host. The advantages of castration of hosts by parasites are discussed using the modified equation in which castration is equivalent to reducing parasite virulence in the host to near zero or zero. It is suggested that castrating parasites can infest a wider range of hosts with higher mortality rates and that within parasite groups having castrating and noncastrating species, the former should infest hosts with higher mortality rates and relatively larger gonads.*

Parasites of many taxa, from protozoans to vertebrates, castrate their hosts. In some groups, such as digenetic trematodes infesting mollusks, castration of the host is the rule (*1*). Ecological life history models have not been used to study this phenomenon. The following general approach is proposed to investigate reproductive strategies of parasites with respect to the advantages of host castration.

Ecological descriptions of life histories use life table data. The life table is an actuarial list of estimations of probabilities of survival to age x, and fecundity in the age

interval x to $x + 1$ for a cohort of organisms born at the same time when $x = 0$. The relationship between age, survival, fecundity, and rate of growth of a population is summarized in the Euler equation in which

$$\sum_x e^{-rx} l_x m_x = 1 \qquad (1)$$

where x is age, l_x is the age schedule of survival probabilities, m_x is the age schedule of fecundity, and r is the rate of growth of the population. The Euler equation is derived from the compound interest law and is valid for successive generations if survival, fecundity, and the relative proportions of individuals in each age group of the population do not change with time (*2*). When data on survival and fecundity are available, r can be computed from successive approximations yielding a value of 1 in Eq. 1.

Equation 1 must be modified to describe a general and simple parasite life history. The survival of the parasite may depend on its effects on the host. To live and reproduce the parasite must take energy from the host, which is gotten by eating its tissues. Eating host tissues must diminish host survival (*3*) and necessarily also survival of the parasite. If maintenance cost of the parasite is small relative to reproductive cost, the extent of damage to the host depends primarily on parasite fecundity. The more fecund a parasite, the lower the survival of the host and also the parasite. Moreover, if the parasite dies prior to reproduction only if the host dies, the parasite survival will depend on the host survival rate and the parasite fecundity. Therefore, selection acting to increase parasite fecundity (for whatever reasons) will simultaneously also decrease parasite survival. Possibly, there may be an optimum parasite fecundity, maximizing the population's growth rate. Higher fecundity would so diminish survival as to reduce r. Fecundity could, in effect, be fixed to a specific maximum depending on the virulence of the parasite and host mortality.

The foregoing hypothesis can be more clearly demonstrated using a modification of Eq. 1 where

$$l_x = e^{-d(1 + vm_x)x} \qquad (2)$$

where d is the mortality rate of the unparasitized host, and v is the virulence of the parasite, measuring the amount by which host mortality increases per unit of parasite fecundity, m_x. Thus, in Eq. 2 l_x decreases exponentially with age at a rate equal to the mortality rate of the parasitized host, $d(1 + vm_x)$. Substitution of Eq. 2 in Eq. 1 yields

$$\sum_x e^{-rx} e^{-d(1 + vm_x)x} m_x = 1 \qquad (3)$$

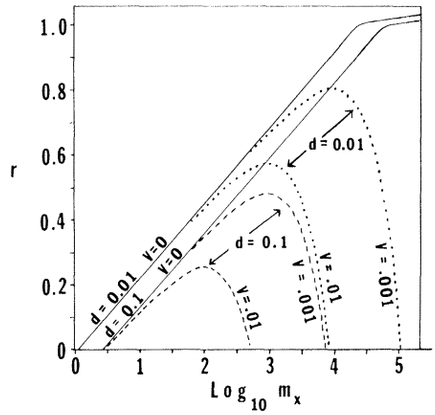

Fig. 1. Relationship between r and m_x for different values of d and v when x is constant ($x = 10$).

If the parasite reproduces only at one age interval and then dies, Eq. 3 can be solved for r directly so that

$$r = \frac{1}{x} \log_e m_x - d(1 + vm_x) \qquad (4)$$

and

$$\frac{\partial r}{\partial m_x} = \frac{1}{xm_x} - dv \qquad (5)$$

The second derivative of Eq. 4 is negative, so r can be maximized for some value of m_x. Setting Eq. 5 to zero and solving for m_x yields

$$m_x = \frac{1}{xdv} \qquad (6)$$

at which r is maximized.

Equation 6 indicates that there is an optimum fecundity, inversely proportional to the product of the age of reproduction, host mortality rate, and parasite virulence, at which the rate of growth of the parasite population is at a maximum. Calculations of r for varying m_x at different values of d and v when x is fixed are shown in Fig. 1. For instance, r is maximized at an optimum fecundity of 100 when $d = 0.1$, $v = 0.01$, and $x = 10$. When v is zero r can increase indefinitely with increasing fecundity whatever the value of d. For positive values of v, parasite growth rate can increase above a fixed value only if the parasite infests a host with lower mortality. The relationship between maximum r at different v and d for fixed x is shown in Fig. 2. In order to maintain r above zero (equilibrium), a parasite with high virulence is restricted to hosts with low mortality rates.

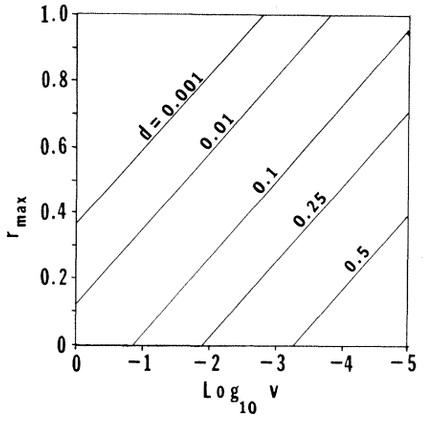

Fig. 2. Relationship between r_{max} and v for different values of d with $x = 10$. For high values of v and d, r_{max} lies below the abscissa.

Two advantages accrue from minimizing virulence. Low virulence increases the maximum r as well as the range of hosts that can be infested. Parasitic castration is the only way of infesting an individual host and reducing virulence to near zero. Infesting other tissues that provide life support for the host decreases host survival. Eating the whole gonad does not increase host mortality as much as eating other tissues does. The limit imposed on parasite growth rate by infestation of the gonads probably depends on the size and regeneration rate of the gonads; since these are limited, the advantage of castration is probably primarily the wider range of hosts, having higher mortality rates, that castrators can infest. This suggests that in closely related groups of parasites, such as genera, within which both castrating and noncastrating species occur, the castrators will infest hosts with generally higher mortality rates, provided reproductive age does not differ much between species. Since r_{max} in castrating species could be limited by host gonad size, it is possible that noncastrating parasites will tend to infest hosts with relatively smaller gonads.

This model is the simplest modification of the Euler equation that takes into account parasite-induced modification of both host and parasite mortality. Assumptions include fixed reproductive age, reproduction at only one age interval (semelparity) in the parasite, exponential survival, relatively low parasite maintenance cost, and parasite mortality only when the host dies. Clearly, parasitic castration would not be advantageous if the parasite were so efficient in finding hosts and so fecund as to infest the entire host population. Studies of optimum host infestation levels and other elaborations of the model should be made. The predictions about life histories of castrators and noncastrators could be verified if systematically collected data on mortality rates of parasitized and unparasitized hosts of parasitic groups having both castrating and noncastrating species were available. To my knowledge, no such information exists for either natural or laboratory populations.

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Reciprocation of Renin Dependency with Sodium Volume Dependency in Renal Hypertension

Abstract. *An angiotensin II inhibitor was administered to rats with two-kidney Goldblatt hypertension. The inhibitor produced a marked drop in blood pressure after 5 weeks but no significant change after 15 weeks of hypertension. However, even after 15 weeks of hypertension, following sodium depletion by either diuretics or a low sodium diet, the animals again became renin dependent as readministration of the inhibitor induced a significant fall in blood pressure. The data indicate that two-kidney Goldblatt hypertension is initially renin dependent but subsequently becomes sodium volume dependent in a way similar, although more protracted, to that already described for one-kidney Goldblatt hypertension.*

Experimental renovascular hypertension exhibits two different pathophysiologic patterns: The two-kidney Goldblatt hypertension (one renal artery clipped with the contralateral kidney left untouched) has been considered typical of renin-angiotensin dependent hypertension in both the initial and the established phase. Elevation of renin and angiotensin II in the plasma has been demonstrated in this model (*1*) in the established phase; at this time the blood pressure can be lowered by the administration of antibodies to, or blockers of, angiotensin II (*2*).

In contrast, the one-kidney Goldblatt model (one renal artery clipped with the contralateral kidney removed) shows only an initial transient renin dependent phase of a few days duration (*3–5*), but then becomes sodium volume dependent in the established phase (*5*) with normal plasma renin and angiotensin II levels and no blood pressure response to blocking agents of or antibodies to angiotensin II. During this phase, sodium deprivation converts hypertension to an overtly angiotensin II dependent type (*6*).

Our study was designed to investigate whether a similar change from a renin dependent to a sodium dependent mechanism occurs with time in the two-kidney Goldblatt model and whether this status can also be reversed by sodium depletion.

A silver clip was placed on the left renal artery of male Wistar rats weighing 140 to 150 g; the right kidney was left untouched. Three groups of animals were studied and all received initially a regular Purina rat chow diet (sodium content 0.22 meq/g). The blood pressure was measured twice weekly by means of the tail microphone method.

The animals in group 1 ($N = 5$) were maintained on the above diet and examined 4 weeks after the clipping. The animals were anesthetized with ether, the femoral vein was cannulated with a PE 10 catheter for the infusion, and the external iliac artery was cannulated with a PE 50 catheter for blood pressure monitoring. Arterial pressure was monitored with a Sanborn pressure transducer. After the animals recovered from the anesthesia, they were kept in a semirestrained position. At the end of a 30-minute control period, the pressure response to an intravenous dose of 100 ng of angiotensin II was determined. Subsequently, [sarcosine^1, alanine^8]angiotensin II (Eaton Laboratories), a highly specific competitive antagonist of angiotensin II (*7*), was infused at a rate of 9 g/min for 60 minutes. After the infusion was discontinued, the blocking effect of the inhibitor was tested by an injection of 100 ng of angiotensin II. The animals were killed 3 hours later when the blood pressure had risen to that observed before the infusion.

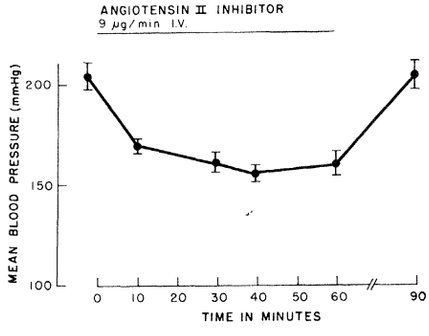

Fig. 1. Blood pressure response to angiotensin II blockage 4 to 5 weeks after the clipping of one renal artery; *I.V.*, intravenous.

The rats in group 2 ($N = 6$) were cannulated 14 to 15 weeks after they were clipped, and the same protocol was followed as described for the animals in group 1. After their recovery from the initial infusion, the animals were maintained in a semirestrained position for another 24 hours, during which time they received an intravenous injection of furosemide (2 mg) and were fed a low sodium diet (*8*) with free access to tap water. Urines were collected, and Na and K determinations made in order to calculate Na and K excretion over a 24-hour period. After this period of sodium depletion, the antagonist infusion was repeated.

The rats in group 3 ($N = 8$) were also kept for a period of 14 to 15 weeks on the regular salt diet. Eight days prior to the experimental treatment they were placed on the low sodium diet, and the antagonist was infused at the end of the 8-day period. Five of these animals were housed in metabolic cages (Acme), and sodium and potassium balance studies were carried out as described (*9*).

In the animals of group 1 (which were kept on the regular salt diet), 4 weeks after clipping, the angiotensin II inhibitor produced an immediate and progressive fall in blood pressure with a decrease of 36.6 ± 4.8 (mean $\pm$ S.E.) mm-Hg after 10 minutes ($P < .01$) and a maximum decrease of 44.0 ± 6.2 mm-Hg after 60 minutes ($P < .01$) (Fig. 1).

In the animals of group 2 (which were also on the regular salt diet), 14 to 15 weeks after clipping the mean of the blood pressures in the controls was similar to that of group 1, but the angiotensin II inhibitor produced no significant change in blood pressure. The maximum decrement in blood pressure was 3.1 ± 3.6 mm-Hg after 60 minutes ($P < .5$) (Fig. 2a). Subsequently, sodium depletion was induced by 24 hours of low salt diet and intravenous injection of 2 mg of furosemide; the resulting loss of sodium was 2.1 ± 0.4 meq, and the net loss in weight was 49.0 ± 7 g, but there was no change in the blood pressure. A second dose of the inhibitor then produced a marked fall in blood pres-