(1971b) results are not inconsistent with our data, and suggest that an antidiuretic factor may be responsible for the effects we observed of dietary Na\textsuperscript{+} content on colonic transepithelial water transport.

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Actions and Metabolism of Corticosteroids in Teleost Fishes
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Teleost fishes arose from actinopterygian stock in the Jurassic period of geological time. The intervening 150 million years or so has seen an adaptive radiation of immense magnitude, and today the Teleostei are numerically the largest discrete group of vertebrates. They vary in size and form from the tiny tropical fish species of a few milligrams to the giant tunny fishes of many kilogrammes to the bizarre fishes of the oceanic depths. Geographically teleosts occur in the icy Antarctic seas, fresh-water lakes and the brine swamps of the Dead Sea, where the osmolarity may be up to 50mL.

The immense and spectacular variety of structure and ecology of teleosts is accompanied by a physiology that, although overtly similar in the group, displays intriguing fickleness in detail (Hoar & Randall, 1969, 1970, 1971). Of particular interest in this respect are the osmoregulatory and body-fluid homeostatic mechanisms, and the endocrine forces that act on them, in stenohaline and euryhaline teleost species. There are three basic osmoregulatory effector organs in teleost fishes: the gills, the kidney and the gastrointestinal tract. Their functions are profoundly affected by a gamut of hormones secreted from the usual recognized endocrine organs such as the hypothalamo-hypophyseal system, the thyroid gland and the adrenocortical homologue, as well as from apparently unique glands such as the corpuscles of Stannius and the urophysis (Chester-Jones et al., 1974).

This present brief review considers the adrenocortical homologue (inter-renal gland) of teleost fishes and the type and rates of production of the corticosteroids, and describes what is known about the physiology and pharmacology of these hormones. In an extensive study Nandi (1962) examined the morphology of the adrenocortical homologue in almost 150 teleost species (from over 80 families) and, on the basis of vasculature, relationship to the kidney and cardinal veins and degree of association with chromaffin tissue, recognized four general types of arrangement. No phylogenetic trends were observed, with morphological diversity being most characteristic.
In no instance has a zonal arrangement of adrenocortical cells, reminiscent of the mammalian adrenal cortex, been observed. On the basis of ultrastructure, histochemistry and the cord-like arrangement of cells, homologies have been made between the teleostean adrenocortical cells and those of the mammalian zonae fasciculata and reticularis, although the zona intermedia has also been considered homologous (Lofts & Bern, 1972). In those species examined (and it must be emphasized that they represent a tiny fraction of the total number available for study) cortisol is quantitatively the major corticosteroid both in blood and synthesized *in vitro*; other products, however, include cortisone, corticosterone, 11-deoxycortisol, 18-hydroxycorticosterone and aldosterone (Sandor, 1969; Idler & Truscott, 1972). Most of these compounds act on osmoregulatory structures, including gills, gut and kidneys, and in less-well-known ways affect carbohydrate and intermediary metabolism as well as reproduction (Chester-Jones *et al.*, 1969, 1972; Henderson *et al.*, 1970). The precise physiological implications of some of the described actions of corticosteroids are not clear, since frequently heterologous hormones are often used, and, further, surgical adrenalectomy is difficult in most teleosts. In one species, the eel (*Anguilla anguilla*), it is possible to remove the adrenocortical homologue surgically and to observe subsequent changes, and thence repair the pathology by using appropriate replacement therapy. The effects of adrenalectomy of eels in fresh water include hyponatraemia and tissue hyperhydration, which result in part from impaired renal excretion of osmotically free water and decreased rates of Na⁺ uptake at the gills. In sea water, adrenalectomized eels are characterized by decreased tissue water, haemoconcentration with hypernaemia; these effects result largely from depressed rates of Na⁺ turnover and malfunction of the gastrointestinal osmoregulatory mechanisms. In the adrenalectomized eel carefully chosen doses of cortisol can maintain normal water and electrolyte balance and also can sustain relative normal renal, branchial and gastrointestinal functions (Chester-Jones *et al.*, 1969).

A number of studies have attempted to relate plasma corticosteroid concentrations to water and electrolyte status in the eel. These, however, have failed to provide conclusive evidence that adrenocortical activity varies with environmental salinity (Hirano, 1969; Ball *et al.*, 1971). The concentrations of cortisol in the plasma of sea-water-adapted eels are similar to those of eels in fresh water. A transitory increment in the cortisol concentration occurs when fresh-water eels are acutely transferred to sea water, but no changes are seen on transfer of sea-water eels to fresh water. These curious findings that the cortisol concentrations (an index of adrenocortical activity) do not change in the face of massive alterations in osmoregularity capacity, and yet cortisol and/or other corticosteroids apparently play key roles in body fluid homeostasis, have been further examined. Techniques to measure secretory and metabolic clearance rates and therefore the effective 'physiological usage' of cortisol have been applied. These methods involve the use of radioactively labelled corticosteroids and measure their dilution by endogenously produced hormone (Owen & Idler, 1972; Leloup-Hatey, 1974; Henderson *et al.*, 1974). The European eel, adapted to either sea-water or fresh-water environments, appears to secrete greater amounts of cortisol under conditions of high Na⁺ turnover and where osmotically free water is at a premium (Table 1).

In the studies by Leloup-Hatey (1974) a single-injection technique with [³H]cortisol was used, whereas those by Henderson *et al.* (1974) employed a constant infusion of [³H]cortisol. The values for metabolic clearance rates qualitatively agree and the derived production rates are quantitatively in excellent accord. A third and more direct method has been employed to examine cortisol secretory rates. In the eel the adrenocortical homologue is set about the cardinal veins, which are then the effective adrenocortical venous effluents (Chester-Jones *et al.*, 1964). It is possible to implant cannulae and collect quantitatively this effluent (cardinal-vein) blood, and to measure the blood flow rate and cortisol concentrations therein. The concentration of steroid in this blood is at least four times that observed in peripheral arterial or venous blood and, further, a clear arteriovenous gradient exists between dorsal-aortic and cardinal-venous plasma cortisol concentrations. In a series of experiments the secretory rates of cortisol were 1.6 ± 0.4 μg/h
Table 1. Cortisol dynamics in the eel (Anguilla anguilla L.)

Key: FW, fresh-water-adapted eels; SW, sea-water-adapted eels.

<table>
<thead>
<tr>
<th>Cortisol metabolic clearance rate (ml/h per kg body wt.)</th>
<th>Plasma cortisol concentration (µg/100ml)</th>
<th>Cortisol production rate (µg/h per kg body wt.)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>FW 40.9 ± 2.2 SW 75.5 ± 2.2</td>
<td>FW 1.9 ± 0.4 SW 1.8 ± 0.4</td>
<td>FW 0.8 ± 0.01 SW 1.4 ± 0.04</td>
<td>Leloup-Hatey (1974)</td>
</tr>
<tr>
<td>20.6 ± 1.3 28.4 ± 2.5</td>
<td>4.1 ± 0.8 4.8 ± 0.4</td>
<td>0.7 ± 0.08 1.3 ± 0.2</td>
<td>Henderson et al. (1974)</td>
</tr>
</tbody>
</table>

per kg body wt. (n = 6) in sea-water-adapted eels and 0.6 ± 0.1 µg/h per kg body wt. (n = 9) in fresh-water-adapted eels. Again the increased adrenocortical activity of animals in sea water is apparent. In transfer experiments, eels transferred from fresh water to full sea water show a slowly rising rate of cortisol secretion over a 24h period; transfer in the reverse direction produced a slow decrease in cortisol production. As mentioned, the steroid concentrations in the cardinal-venous blood are considerably greater than the usual peripheral blood concentrations, and as a result it is possible to detect steroids not readily measured in peripheral blood. Recently, in a series of experiments employing 'stepwise' transfers from fresh water to sea water, new materials as yet not fully identified have been shown to occur in concentrations slightly below those of cortisol. When the environmental salinity becomes hyperosmotic to blood (above 300mosm), a steroid, which is not cortisol, aldosterone or corticosterone, begins to appear. Cortisol may thus not be the only corticosteroid responsible for osmoregulatory adaptation to sea water, and indeed the steroidogenic patterns of sea-water-adapted and fresh-water-adapted eels may differ in more fundamental ways than previously thought.

Various trophic agents may participate in the physiological regulation of the teleost adrenocortical homologue. Again, only one or two species have been examined. A hypothalamo–hypophysal–adrenocortical axis is present. Hypophysectomy or injections of dexamethasone depress plasma cortisol concentrations and its measured secretory rates, and mammalian adrenocorticotropic hormone restores the deranged situation (Donaldson & McBride, 1967; Henderson et al., 1974). The corpuscles of Stannius have an undoubted role in osmoregulation of teleost fishes, but it is not known whether their secretion(s) act(s) directly on osmoregulatory effector systems or indirectly by actions on other hormone production rates (Chester-Jones et al., 1969). A corpuscle-of-Stannius–adrenocortical axis has been suggested, but functions in ways not altogether clear (Leloup-Hatey, 1970; Fenwick & Forster, 1972; Henderson et al., 1974).

A renin–angiotensin system exists in most if not all vertebrates (Sokabe & Ogawa, 1974), and participates in fluid and electrolyte metabolism either directly on the osmoregulatory structures or indirectly by actions on the output of other hormones, including those of the adrenocortical homologue (Sokabe, 1974). In sea-water-adapted eels plasma renin activity is some 9.9 ± 1.3ng-equiv. of angiotensin II/ml (n = 19), whereas in eels adapted to fresh water there is 3.8 ± 0.4ng-equiv./ml (n = 21). Further, it has been found that injections of partially purified eel kidney extracts can potently increase plasma cortisol concentrations and elevate the blood pressure of both fresh-water- and sea-water-adapted eels. The elevated plasma renin activities in sea-water eels may be associated with the increased adrenocortical activity or with the depressed glomerular filtration rates.

In conclusion, the function and metabolism of corticosteroids in teleost fishes are fields of study in which much information is presently available, but there remain large
areas of ignorance. The exact sites of action of the steroids, their interactions with hypophysial, renal and other hormones as well as with the corpuscles of Stannius are all arcane and require further elucidation.

Hoar, W. S. & Randall, D. J. (eds.) (1969) *Fish Physiol.* 1–3
Hoar, W. S. & Randall, D. J. (eds.) (1970) *Fish Physiol.* **4**

**Secretion of Testosterone and Corticosteroids by the Adrenal Cortex in the Marsupials *Trichosurus vulpecula* and *Didelphis virginiana* and in the Rat, and the Effects of Adrenocorticotrophin and Gonadotrophin Stimulation in vitro**

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It is widely accepted that in addition to corticosteroids the mammalian adrenal cortex is a source of androgens. In many species, including man, dehydroepiandrosterone, dehydroepiandrosterone sulphate, androstenedione and 11β-hydroxyandrostenedione are prominent products (see Vinson & Whitehouse, 1970), and testosterone has also been identified, although in smaller amounts (Kase & Kowal, 1962; Ward & Grant, 1963).

Two aspects of adrenal androgen production have received comparatively little direct study. (1) Is the production of androgens limited to any particular zone or cell type in the adrenal cortex? (2) What is the nature of the mechanisms that control adrenal androgen secretion and how do they relate to the control of corticosteroid secretion?

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