Shock and Compensatory Mechanisms, Diagnostic Considerations

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It is widely accepted that birds which are presented depressed and with fluffed feathers, apparently suffering from acute onset of illness are usually showing the signs of endstage chronic disease. The early stages of disease are masked by the birds so that only the endstage processes are obvious to most owners. This presentation aims to discuss some of the mechanisms that allow birds to deal with insults that would otherwise result in shock. Some of the mechanisms are similar to mammalian ones, but differ in their importance, whereas others have no mammalian equivalents.

Renal Mechanisms

There are three mechanisms within the avian kidney which allow the bird to deal with circulatory embarrassments such as haemorrhage and dehydration. These are (A) recruitment of mammalian-type nephrons, (B) reduction of glomerular filtration rate (GFR) and (C) increased absorption of water and electrolytes from the glomerular filtrate. All these changes are largely mediated by arginine vasotocin (AVT), the avian antidiuretic hormone. Other hormones such as mesotocin, aldosterone and the renin-angiotensin complex may be involved but their roles in birds have not clearly been defined.

A brief outline of the relevant features of avian anatomy should be discussed, as the function of the renal mechanisms is a reflection of anatomical structure. The avian kidney comprises two sets of nephrons; the mammalian type nephrons (MTNs) and the reptilian-type nephrons (RTNs). The main differences between these nephrons are as follows, (1) MTNs possess a loop of Henle, with thick and thin limbs, whereas RTNs do not, (2) MTNs have convoluted proximal and distal tubules, while the tubules of RTNs are fairly simple and (3) MTNs are arranged parallel to each other and their loops of Henle are bound with the vasa recta into medullary cones by connective tissue. This, along with the osmotic gradient that occurs in the medullary cones, enables countercurrent exchange to occur in MTNs and thus urine can be concentrated as it passes through the loop of Henle. By contrast, since RTNs are not arranged in parallel and are confined to the renal cortex, they can only produce urine that is isotonic or hypotonic to plasma. However, all collecting ducts pass though a medullary cone in their path towards a ureter, so that urine can be concentrated to some extent regardless of which nephrons it originates from.

The relative proportions of MTNs and RTNs in the kidney vary between species. For instance 90% of the nephrons are of the reptilian type in starlings (*Sturnus vulgaris*), whereas in the desert-dwelling Gambel's quail (*Lophortyx gambelli*) only 70% of nephrons are of the reptilian type. Generally, desert-dwelling species of birds, and birds with limited access to fresh water have more MTNs than species which live in areas with ready access to water. In some species, up to 40% of the nephrons are of the mammalian type.

The arterial blood supply to the avian kidney follows roughly the same pattern as that in the mammalian kidney, renal arteries branch into interlobar arteries, which divide into interlobular arteries, which give rise to intralobular arteries. It is the intralobular arteries from which the afferent glomerular arterioles arise. However, in birds the intralobular arteries also occasionally give rise to large-diameter branches (shunting arterioles) which join the peritubular capillary network.

In response to hypovolaemia or a shortage of water, as might occur if a bird is deprived of drinking water, refuses to drink due to illness or loses more water than it can replace, plasma osmolality rises. This stimulates secretion of AVT which initially causes constriction of the afferent glomerular arterioles of the RTNs. As a result, the nephrons least able to concentrate urine are no longer functioning and the urine flow in the collecting ducts is reduced by about 40%.

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Secondly, the shunting arterioles dilate, diverting the blood supply of the RTN glomeruli to the peritubular network, which is involved with tubular secretion of uric acid and other compounds. This is one of the factors that allows birds to continue excretion of uric acid when glomerular filtration is greatly reduced.

Thirdly, the MTNs, not all of which are functional during hydration, are recruited, so that glomerular filtration continues but only in those nephrons which are most capable of producing concentrated urine.

Overall, glomerular filtration is reduced. The fact that more MTNs are functioning increases the efficiency of the medullary osmotic gradient, so that more concentrated urine can be produced. Finally, AVT increases both the resorptive capacity of the ascending loop of Henle and the distal convoluted tubule, as well as increasing the permeability of the collecting ducts. Since there is a decreased flow in the collecting ducts, there is more time for the urine within them to equilibrate with the surrounding hyperosmotic interstitial fluid within the medullary cones, and thus produce urine which, in some species can be up to 2.6 times the osmolality of plasma.

Renal Portal system

The renal portal system is a feature which birds share with reptiles, but which is lacking in mammals. It consists of a ring of veins which receive blood from the pelvic limb, the colon and some of the structures in that region. The renal portal ring is connected to the hepatic portal system by the coccygomesenteric vein, to the caudal vena cava and to the intervertebral venous sinuses. Normally, most of the blood that the renal portal system receives flows into the kidneys, where it mixes with blood from the efferent glomerular arteriole and participates in perfusion of the peritubular network.

The renal portal system is not simply a blood vessel. It contains a valve on each side which is positioned so that, when closed, it prevents blood from flowing directly into the caudal vena cava. When it is closed, which is usually the case, blood flows either into the kidney or via the coccygomesenteric vein into the hepatic portal system towards the liver. The proportion of blood that flows to each organ is inversely proportional to the resistances to flow in the two organs (for example if the resistance in the liver is 8 arbitrary units and the resistance in the kidney is two arbitrary units, then the kidney will receive 80% of the flow, and the liver 20% of the flow.) However, if the portal valve is open, the blood which enters the renal portal circle is shunted away from the kidneys and directly into the caudal vena cava. It has been shown that the smooth muscle of the renal portal valve is innervated by both adrenergic and cholinergic fibres and is inhibited (that is, the valve opens) in response to adrenaline. Thus, in a situation where the sympathetic system is dominant, for example during pursuit by a predator or in traumatic shock, blood is diverted away from the kidneys and is available to meet the increased demands on the cardiovascular system.

Tolerance to Altered Physiological Status

In addition to an impressive arsenal of compensatory mechanisms, birds also display a remarkable tolerance to altered physiological parameters. A recent study has demonstrated that heat-acclimatised pigeons exposed to both heat stress and dehydration can lose 30% of their body water (18% of their body mass, assuming 60% water composition), experience plasma osmolality elevations of 30% (from 335 mOsm/kg to 437 mOsm/kg) and a rise in body temperature of 3ºC but maintain normal behaviour. When these birds were subsequently given drinking water, they recovered 97% of their body weight loss. Unacclimatised pigeons, starlings and budgerigars have also been shown to experience increases in plasma osmolality of around 35 mOsm/kg (from 306 to 345 mOsm/kg for pigeons, 345 to 378 mOsmol/kg for starlings and 324 to 365 mOsmol/kg for budgerigars). These changes are potentially fatal to mammals.

Redistribution of Blood Flow

Several studies in pigeons, ducks and chickens have been carried out in which the distribution of blood flow is evaluated in health and in shock. Most authors agree that the musculature, especially the flight muscles, normally receive a disproportionately large supply of the cardiac output. Since the muscle is not very metabolically active at rest, much of the oxygen carried by the blood is not taken up by the muscle cells, resulting in a small arterio-venous (A-V) oxygen difference. If the musculature becomes active, that is, if the bird should fly, this A-V oxygen difference increases. Thus, the venous oxygen reserve functions as a reserve which is consumed during activity. However, this reserve capacity is also utilised if the bird enters compensated shock.

Studies have shown that if a bird is bled or dehydrated, several changes occur in the muscles. Firstly, vasoconstriction decreases the blood supply. As a result more blood is available to the essential organs, as in mammals, but there is a decreased oxygen reserve available to the muscles. Secondly, a change in the pre- and post-capillary blood pressure occurs, in such a way that there is a decreased hydrostatic pressure in the capillary so that isotonic fluid is drawn from the interstitial compartment into the plasma. This fluid is in part replaced by intracellular fluid, so that the net result is maintenance of plasma volume at the expense of interstitial and intracellular fluid. Thirdly, unlike mammals, birds maintain their blood volume rather than blood pressure during heamorrhage.

Thus birds maintain the functional integrity of the cardiovascular system at the expense of the functional reserve and cellular water of the flight apparatus. While it has not been tested, it seems logical to assume that birds in this compensated state, even without the additional stresses of sepsis, endotoxaemia or starvation, would be less able to fly and have a reduced ability to deal with stress and sympathetic outflow.

Suggested Blood Analysis Profile

For a long time, the evaluation of the health of avian patients has been modelled on that of mammalian patients. As a result, packed cell volume (PCV), total plasma protein (TP) and plasma sodium concentration have been used to determine fluid and electrolyte imbalances. Recently, several studies have indicated that these are not particularly useful in the avian patient. Likewise, recent studies have shown that uric acid is not a valuable indicator of prerenal renal failure (shock). Instead, osmolality has been shown to be both reliable and useful in assessing dehydration, as normal values vary little between individuals and even between species. Also, osmolality rises directly with the degree of dehydration, so that a 15% increase in osmolality indicates 15% dehydration.

Urea, which was not thought to be of diagnostic value in birds (whichmainly excrete uric acid rather than urea), has emerged as a reliable indicator of decreased renal perfusion. The reason for this is that uric acid continues to be excreted in the absence of arterial blood supply to the kidney, whereas urea is excreted solely by glomerular filtration. Furthermore, urea will diffuse back into the peritubular capillaries if tubular flow is decreased. Uric acid levels in the blood will only rise if the kidneys fail completely or if the shock is of renal rather than prerenal origin. Urea is, therefore, a sensitive indicator of decreased renal flow and, in combination with uric acid can alert the clinician to problems in the kidneys.

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