Chapter I

REVIEW OF LITERATURE

Beall, Cooley, Morris and Moyer (1957) presented the results from renal function studies in 8 patients examined before, during and after extracorporeal circulation in normothermia without haemodilution. A modified de Wall-Lillehei bubble oxygenator with a flow rate of 35 ml/min/kg bw was used. During induction of anaesthesia, glomerular filtration rate, (inulin clearance) and renal blood flow (PAH clearance/haematocrit) were 77 and 74% of control values. During opening of the chest, a certain normalization of both glomerular filtration rate and renal blood flow took place. When extracorporeal circulation was established, glomerular filtration rate and renal blood flow decreased to 29 and 23%, respectively of control values, regaining on completion of operation 92 respectively 73% of initial values. Urine flow and electrolyte excretion were only slightly affected by anaesthesia and operation. During extracorporeal circulation, however, urine flow decreased to 33%, and urinary sodium and potassium excretion to 50% of control values. After cardiac bypass sodium excretion remained at a low level, while potassium excretion increased to double control value on completion of operation.

Morris, Witt, Cooley, Moyer and DeBakey (1957) studied renal haemodynamics in 11 patients under the same conditions and with the same technique as Beall et al. Mean aortic pressure of 80–90 mm Hg was recorded in all measurement periods except during extra corporeal circulation, when aortic pressure averaged only 44 mm Hg. Total blood flow from the heart-lung machine was then 35 ml/min/kg bw. Simultaneously, renal blood flow was reduced to 24% and glomerular filtration rate to 29%. The corresponding values after cardiac bypass were 72 respectively 80%.

A total blood flow of more than 60 ml/min/kg bw was necessary if tissue oxygen tension level in the kidney was to be maintained during extracorporeal circulation. Schwartz, De Weese, Niguadula, Gabel and Mahoney (1959) concluded this from experiments on dogs in normothermia without haemodilution.

Jontz, Bounous, Heimburger, Su, Teramoto, Shumacker and Onnis (1960) found in dogs that renal blood flow at any given flow from the heart-lung-machine (total cardiac bypass without haemodilution) was approximately the same in normothermia and hypothermia (30°C). Renal blood flow represented a higher percentage of the corresponding value prior to extracorporeal circulation in hypothermia compared with normothermia (direct measurement of renal blood flow in graduated cylinder).
With clearance procedures in dogs (Senning, Andres, Bornstein, Norberg and Andersen 1960), and in man (Replogle and Gross 1960) a direct correlation was found between total flow from the heart-lung machine and renal blood flow during extracorporeal circulation in normothermia without haemodilution. Senning et al also observed that, even with high blood flow (100 ml/min/kg bw), renal blood flow, glomerular filtration rate and electrolyte excretion during extracorporeal circulation were significantly reduced. Renal blood flow was estimated on the basis of clearance and extraction ratio of PAH.

Doberneck, Reisner and Lillehei (1962) analysed the incidence of renal failure in 1000 patients who underwent operation in extracorporeal circulation. Thirty patients developed acute renal failure, and 26 of them died. Oliguria and very rapidly rising BUN and serum potassium were characteristic for postoperative renal failure. Hypotension and arrhythmia before, during and after operation, rather than extracorporeal circulation as such, were regarded as causes of renal failure.

From an investigation in 1963 (Smith, Berman and Chisholm), covering 27 patients, it appeared that glomerular filtration rate (endogenous creatinine clearance) estimated immediately after extracorporeal circulation (normothermia without haemodilution) was reduced to approximately 50% of the value prior to operation. Simultaneously, sodium excretion decreased considerably. Three days later glomerular filtration rate was still not fully restored. Mannitol was used in some patients from start of operation.

In a comprehensive study of 37 patients with acquired valvular heart disease, Grismer, Levy, Lillehei, Indeglia and Lillehei (1964) reported on renal function before and after operation with extracorporeal circulation (hypothermia and haemodilution with low molecular weight dextran). Four hours after operation, glomerular filtration rate (endogenous creatinine clearance) in all patients was lower than corresponding preoperative values. A further decrease was recorded in several cases 24 hours after operation, and when the patients were discharged from hospital many of them still had reduced glomerular filtration rate compared with preoperative values. Postoperative renal plasma flow (PAH-clearance) showed a considerable range and no definite tendency. Reduced serum sodium, but unaffected potassium, were recorded in the majority of cases. Sodium excretion in urine fell and potassium excretion rose in the immediate postoperative course. It is noteworthy that 8 of the 37 patients in this study developed postoperative renal insufficiency. Long perfusion and low blood flow together with high plasma haemoglobin level were, according to the authors, contributory causes of postoperative renal insufficiency.

Norman, McDonald and Sloan (1964) showed that of 333 patients, who were operated upon with heart-lung machine in hypothermia (30°C) without haemodilution and who survived more than 48 hours, 10 developed acute renal failure. Three of these 10 patients died. The authors ascribed the
high survival rate to an early induction of peritoneal dialysis. Factors during perfusion, which were of significance for postoperative renal failure, were long perfusion, severe blood loss, low perfusion rate, pronounced hypothermia, clamping of the aorta and ventricular fibrillation.

YEH, BRACKNEY, HALL and ELLISON (1964) studied 180 patients who had undergone open-heart surgery, as a rule without haemodilution and with varying degrees of hypothermia. Seventeen patients showed signs of post-operative renal damage, and 10 of these could be characterized as “tubular necrosis”. Only one patient in this material died in renal failure. Low blood flow during extracorporeal circulation, particularly in combination with hypothermia, excessive haemolysis, long perfusion and low postoperative pH in blood were factors which contributed to acute renal failure. On the other hand, it was concluded that acute renal failure could be avoided with high flow rate, relatively short perfusion and low haemolysis.

According to ETHEREDGE, LEVITIN, NAKAMURA and GLENN (1965), glomerular filtration rate (endogenous creatinine clearance) usually decreased during extracorporeal circulation. In 12 of the 18 patients studied there was simultaneously a reduction of urine flow and sodium excretion, but in the remaining 6 patients, despite decrease in glomerular filtration, increases in urine flow and sodium excretion were recorded during extracorporeal circulation. Continuous mannitol infusion was used throughout operation. It is not stated whether hypothermia was used.

KAHN, CERNY, LEE and SLOAN (1965) found in 30 patients that glomerular filtration rate (inulin clearance) and renal plasma flow (PAH-clearance) during total cardiac bypass were reduced to 33% respectively 50% of values prior to operation. Both renal plasma flow and glomerular filtration rate had regained normal values one hour after operation and 24 hours later exceeded preoperative values. The same pattern appeared whether whole blood or haemodilution with low molecular weight dextran was used in the heart-lung machine. On the other hand, if the machine was filled with blood plus mannitol, glomerular filtration rate still decreased during extracorporeal circulation, while the reduction in renal plasma flow was precluded. Moderate hypothermia (32°C) was used during extracorporeal circulation in all these cases.

MIELKE, MAHER, HUNT and KIRKLIN (1965) examined renal function before, during and after extracorporeal circulation in 7 patients operated upon for aortic valvular lesions in normothermia with haemodilution (glucose with sodium chloride). Urine flow fell during halothane anaesthesia and operation before extracorporeal circulation in the majority of patients. After an initial oliguric phase, there was a considerable rise in urine flow during extracorporeal circulation. Glomerular filtration rate (inulin clearance) decreased to almost 50% during anaesthesia and operation, but no further decrease was noticed during extracorporeal circulation. There was a progressive restitution of glo-
merular filtration rate after cardiac bypass, but usually preoperative values were not reached until 2 days after operation. Renal plasma flow (PAH-clearance) showed a similar initial fall, but later a tendency to rise during and immediately after extracorporeal circulation. Generally renal plasma flow also had a complete normalization two days after operation. Urine osmolality decreased and osmolal clearance increased during extracorporeal circulation. Tubular reabsorption of free water was low during the same period.

NORDLUND (1966) found in 181 patients, operated upon with heart-lung machine, that glomerular filtration rate (endogenous creatinine clearance) was reduced to about 20% during extracorporeal circulation compared with preoperative values. In the majority of these patients, glomerular filtration rate was normalized on the first postoperative day. Eighty-nine patients had reduced renal function postoperatively, but only 15 of these could be classified as acute renal failure. Peroperative factors of significance in this connection were low urine flow, prolonged perfusion and low oesophageal temperature. On the other hand, high urine flow during operation was of primary importance in precluding postoperative renal failure. Priming of the heart-lung machine with blood plus mannitol or blood plus mannitol plus low molecular weight dextran gave the best result in this respect.

In an investigation at these clinics, JOHANSSON, LUNDBERG and SÖDERLUND (1967) found that, in 59 out of 423 operations (11%) performed between 1960 and 1966 with extracorporeal circulation and moderate hypothermia, the postoperative course was complicated by impaired renal function. Thirteen of these patients (3%) had severely impaired renal function with oliguria and rapidly increasing uraemia, and all except one died. The remaining 46 patients had postoperatively no oliguria and moderate, mostly transient uraemia. Among the patients with impaired renal function, a high plasma haemoglobin level, a low peroperative arterial pressure and low urine flow was often found. During the period 1960-1966 technique and equipment for extracorporeal circulation were improved, haemodilution was introduced, and plasma haemoglobin concentrations achieved at these operations were considerably reduced. Probably as a consequence thereof the incidence of impaired renal function was lower among patients operated upon between 1963 and 1966 than among those operated upon between 1960 and 1962.

In summary. The great variation of methods and circumstances at the different examinations hardly permits any general conclusions regarding renal function during open-heart surgery. A more or less pronounced reduction of urine flow, glomerular filtration rate and renal excretion of electrolytes seems, however, to be common during open-heart surgery and particularly during extracorporeal circulation. Renal blood flow generally decreases under the influence of anaesthesia and operation, but the results during cardiac bypass are conflicting.

An adequate preoperative hydration is of importance in precluding renal
failure after open-heart surgery. Among the decisive factors during cardiac bypass are high urine flow, short perfusion, high flow rate, temperature $> 30^\circ C$ and atraumatic perfusion with low plasma haemoglobin. Normal cardiac output is a necessary prerequisite for maintaining adequate renal function after operation.