Third edition

Techniques in Extracorporeal Circulation

Edited by

Philip H Kay

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Techniques in Extracorporeal Circulation

Publisher's Preface

In the years which have elapsed since the publication of the second edition of Marian Ionescu's *Techniques in Extracorporeal Circulation* there have been many advances in technology and thought on the topic, and these are reflected in the contents of this new edition, edited by Philip Kay. Drawing on an international team of contributors, the book is an essential reference for cardiothoracic surgeons, anaesthetists, perfusionists and support staff.

Preface to Third Edition

The heart is a unique organ, simple in concept as a muscle pump, but complex in design and function. Heart failure, from whatever cause, remains the commonest cause of death in the western world.

It is now almost 100 years since von Reyn contravened the dictates of Billroth, risked 'loosing the esteme of his colleagues' and successfully operated on the heart. However cardiac surgery proceeded at a slow pace until the development of the extracorporeal circuit. Thereafter the understanding of the complex anatomy, biochemistry, pharmacology and physiology of the heart has enabled us to take great strides in the complex repair work that is now so common place in the operating room. Concomitantly, advances in rheology and material science have provided a wider safety margin and therefore expanded the number of patients able to benefit from cardiac surgery. It is these advances that form the basis of the third edition of *Techniques in Extracorporeal Circulation.*

The first edition of this book, edited by Mr M. Ionescu and Mr G. Wooller 16 years ago laid a solid foundation for the student of extracorporeal circulation. It was followed by a second edition five years later and after a further 11 years by this edition. Yet progress in this field is so fast that many of the new developments in this book were not even contemplated in the final 'future developments' chapter of the second edition and so I am sure will be the case for the fourth edition. Similarly much progress has been made during the three years it has taken to produce this book. Nevertheless, this edition, like the original, provides a firm basis for doctors, nurses, perfusionists and physicians assistants alike, all students of the extracorporeal circulation and its ever increasing number of applications.

I hope that it will stimulate its readers to continuing the pioneering interface between the lone surgeon and the increasingly complex machinery that surrounds him.

P.H. Kay

Preface to Second Edition

The preface to the first edition of this book was preceded by Michelangelo's humble remark 'ancora imparo'. Even for the contents of this small book on techniques in extracorporeal circulation it proved its timeless veracity as we 'continue to learn'.

The first edition however, despite many shortcomings, has fulfilled its role.

During the past few years the energetic clinical and research activities have led to many advances and have further broadened the concept of artificial circulation and oxygenation so that an increasing number of subspecialties are now attaining a certain contour.

In recent years, several areas of extracorporeal circulation have assumed increasing importance. The progress made in the field of ischaemic heart disease and the major impact of myocardial protection through cardioplegia are only two of the most obvious examples. Refinements in the construction and performance of bubble oxygenators and the introduction of disposable membrane oxygenating systems have changed the techniques of heart–lung bypass and broadened its scope.

Many pioneers in these fields have discovered and rediscovered noteworthy features of great clinical significance.

This second edition attempts to summarize the major technical problems and touches on some of the more theoretical aspects of extracorporeal circulation but does not necessarily provide final answers.

In an effort to keep abreast of the many advances which have occurred, a number of additional topics have been included in this present edition. Several new, outstanding contributors have participated, whilst the great majority of those chapters which appeared in the first edition have been updated or augmented.

Despite the awareness of discontinuity and reiteration, this second edition of *Techniques in Extracorporeal Circulation* retains the structure of most modern books by being comprised of a series of individual chapters.

I wish to express my enthusiasm for the privilege of editing this text and gratefully acknowledge the outstanding contributions of the authors who have joined in this endeavour.

I should like to thank Miss Wendy Lawrence for the complex and seemingly endless secretarial work.

My sincere appreciation is extended to Messrs Butterworths for their unfailing attention to detail and for the maintenance of the high standards for which they are known.

Marian I. Ionescu

Preface to First Edition

ancora imparo
Michelangelo Buonarotti

Extracorporeal circulation with an artificial heart-lung machine has established itself as the routine adjunct to intracardiac and vascular surgery. Since its introduction in 1953 this method has been progressively improved by development and simplification of the equipment and by better understanding of the body response to the alterations induced by the use of artificial perfusions.

The method, established in the experimental laboratory, has been perfected by clinical use. For many poorly understood aspects the method has continued to be investigated in the laboratory, where answers and solutions have been found for innumerable bewildering and knotty clinical problems.

A superficial look at today's methods would give the uninformed the general impression that no substantial progress has been made in the past ten years. For example, the same principle of bubble oxygenation used at the beginning of the open-heart surgery era is almost universally employed today. The same may be said for metallic prosthetic valves with a ball or disc occluder mechanism. The best method for 'myocardial preservation' during open-heart surgery is yet to be established and the Montagues of hypothermia still have to convince the Capulets of coronary perfusion of the veracity and superiority of their principle just as much as they had to ten years ago.

On closer examination, one realizes that during the past ten years an enormous wealth of data and knowledge has been accumulated and the application of this knowledge has made clinical perfusions incomparably better and safer. The results of cardiovascular surgery obtained today, whether in the newborn or the elderly, for great arteries or coronary arteries, in routine cases or in emergencies, when compared with the results obtained only ten years ago, are the best proof of progress and continuous improvement in extracorporeal circulation.

During the past few years many new and exciting principles and techniques based on extracorporeal circulation have been brought into clinical use. Deep hypothermia for heart surgery in the newborn, prolonged extracorporeal oxygenation-perfusion for pulmonary insufficiency and intra-aortic balloon pumping for circulatory assistance are some of the major achievements of the past decade.

The paucity of books devoted exclusively to extracorporeal circulation has prompted us to bring together in a single volume standard *current techniques in extracorporeal circulation* along with the more recent developments in this field. This is an attempt to answer some of the innumerable practical problems associated with the routine use of artificial circulation and oxygenation and to present some models of standardized techniques.

A major problem with such a book is to decide what to include and what to omit. We are aware that omissions have been made but we have aimed to keep the subject matter strictly circumscribed in the interest of text size and readability. The esoteric has been omitted on purpose and emphasis is placed on the current practical methodology.

Advances in modern surgical and perfusion techniques have been developed to such a degree that an entirely new spectrum of problems evolves with each new development. Such rapid changes and improvements will certainly call for another publication in the near future and this is another reason for limiting the size of this book.

Since this is a multi-authored book and the chapters are designed to be read separately, some reiteration has been inevitable, although an attempt was made to avoid repetition.

Major attention has been focused on the cardiovascular system, the lung, the renal function and haematological changes. Clearly the brain, liver, gut, muscle masses and reticuloendothelial system are of great importance in the body response to extracorporeal circulation but the measurement of their function in the cardiovascular patient is at the moment largely in the realm of the investigator. Although the principles and techniques described have become routine for practical purposes, they are by no means beyond challenge. As William Hazlitt put it 'when a thing ceases to be a subject of controversy, it ceases to be a subject of interest'.

The Editors join the contributors in hoping that this volume will be of interest to those active in the field of cardiovascular surgery.

We take great pleasure in expressing our thanks to Dr Frank Gerbode for kindly writing the Foreword of this work. We are grateful to Miss Nancy Evans for her continuous and enthusiastic help.

Completion of this book within a few months was promised, but it has taken almost two years and we appreciate the forbearance and continuous help of our publishers, Butterworth and Co. Ltd.

M.I. Ionescu

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Contents

Publisher's Preface vii
Preface to Third Edition ix
Preface to Second Edition xi
Preface to First Edition xiii
List of Contributors xv

1 Historical aspects 1
S.A. Livesey and S.C. Lennox
2 Physiology and pathophysiology of extracorporeal circulation 8
Robert H. Bartlett and Ralph E. Delius
3 Design and principles of the extracorporeal circuit 33
L. Bigi, N. Ghelli, A. Menghini and I. Panzani
4 Membrane and bubble oxygenators 42
Marc E. Voorhees and Roger Elgas
5 Filtration in cardiopulmonary bypass 56
Linda Marshall
6 Priming fluids for cardiopulmonary bypass 72
Mahesh V. Shah
7 Anaesthetic techniques for cardiopulmonary bypass 78
J.W.W. Gothard
8 Intraoperative myocardial protection 88
Simon J.M. Ledingham
9 Postoperative management following cardiopulmonary bypass 138
Martin K.G. Boylan
10 Haematological aspects of extracorporeal circulation 144
Mano S. Raja and Alan F. Penny
11 The role of the complement system during cardiopulmonary bypass 156
R.S. Bonser and D. Vergani
12 Changes in renal function associated with cardiopulmonary bypass 178
F.D. Thompson
13 The neurological sequelae of cardiopulmonary bypass 183
Peter Smith
14 Microbiological aspects of heart, heart–lung and lung transplant patients 194
Roger Freeman and Frances Kate Gould
15 Blood conservation following cardiovascular surgery 205
Altagracia M. Chavez and Delos M. Cosgrove III
16 Pulsatile flow during cardiopulmonary bypass 211
David Bregman, Michael Kesselbrenner and Jeffrey B. Sack
17 Low flow and circulatory arrest 230
P.H. Kay
18 Intra-aortic balloon counterpulsation 236
Michael Kesselbrenner, Jeffrey B. Sack, Robert A. Saporito Jr and David Bregman
19 Ventricular assist devices 268
Timothy Locke and Christopher McGregor
20 Artificial hearts – present and future 282
W.J. Kolff and Jack Kolff
21 Heart and heart–lung transplantation 299
G. Fradet, J.P. Scott, T.R. Graham, R.L. Smyth, E. Solis and J. Wallwork
22 Extracorporeal respiratory support 309
John H. Dark
23 Future developments and potential applications of extracorporeal circulation in medicine and surgery 321
Hans Zwart
Index 331

1

Historical aspects

S.A. Livesey and S.C. Lennox

The progress of cardiac surgery over the last four decades will have delighted and amazed the pioneers whose work is briefly described in this chapter. From operating on only the most parlous patients with end-stage congenital heart disease the specialty has developed into a routine service with a minimal morbidity and mortality; this owes much to the development of a safe, reliable and versatile method of maintaining the circulation using extracorporeal support.

The concept of external support of the circulation has been with us for nearly two centuries. At the end of the eighteenth century physiologists were aware that the function of certain organs – the nervous system and muscles – could be restored after death by perfusing these organs with blood. In the mid-nineteenth century Brown-Sequard (1858) used his own blood to perfuse an animal limb and was able to restore local reflexes.

The concept of artificial oxygenation developed a little later. After several workers had shown that blood could be 'arterialized' by bubbling oxygen through it, von Frey and Gruber (1885) developed the first 'heart–lung' machine in 1885. In this machine blood was allowed to form a film on the inside of a hollow metal cylinder where it was exposed to oxygen. Later that century in 1895 Jacobj used an isolated animal lung as an oxygenator.

From the mid-nineteenth century it was apparent that untreated blood could not be used to maintain artificial perfusion because it clotted, so it was rendered incoagulable by whipping (which results in defibrination) and then it flowed freely. It was not until the discovery of heparin by McLean in 1916 that perfusion science could begin to make significant advances.

The development of satisfactory pumps was more troublesome to early workers in the field than was the development of oxygenators. Rubber balloons and various camshaft mechanisms were initially used but it was the development of the Dale–Schuster valved pump and later the DeBakey roller pump that allowed this aspect of perfusion to develop. The controversy over pulsatile and non-pulsatile perfusion has long been present. Hamel (1888) and Jacobj (1890) were aware of the desirability of pulsatile flow and constructed several elaborate devices to achieve this.

Much of the early drive in the development of extracorporeal techniques came from physiologists but they were to a certain extent unaware of the adverse effects various materials had on blood and sterility did not feature in early experiments. Unrecognized sepsis may have accounted for some instances of circulatory failure that were at the time thought to be a direct consequence of perfusion *per se*.

Although many scientists were working on techniques of extracorporeal circulation throughout the world, the credit for their introduction into clinical practice should go to Kolff who pioneered haemodialysis using an artificial kidney (1944) and to Gibbon (1954) who successfully repaired an atrial septal defect in a young woman in 1953 with the circulation totally supported by an extracorporeal pump oxygenator system.

Methods of oxygenation

Many methods of artificial oxygenation of blood have been investigated over the last century starting from the direct injection of oxygen into the bloodstream, to the use of chemicals to generate oxygen, proceeding to the film oxygenators which were used in the heyday of cardiac surgery and finally to the modern bubble and membrane oxygenators in use today.

In an experiment in 1811 Nysten injected oxygen intravenously into dogs breathing pure nitrogen and was able to prolong their survival by several minutes but no longer. Similar experiments in the twentieth century (Bourne and Smith, 1927) showed that the amount of intravenous oxygen needed to raise the oxygen saturation significantly resulted in circulatory embarassment due to gaseous pulmonary emboli. The concept was later extended by Singh (1935, 1960) who used hyperbaric chambers to increase the solubility of the injected oxygen and used the technique clinically along with hypothermia to reduce the patient's oxygen requirements.

The administration of oxygen by the subcutaneous or intraperitoneal routes was found to be of no value in raising the blood oxygen tension (Bourne and Smith, 1927).

The concept of using chemicals to generate oxygen has also been investigated. The injection of hydrogen peroxide intravenously produced severe hypertension though the use of dilute solutions was tried clinically (Abeatici, 1959). Injecting a solution of sodium percarbonate which degrades to produce oxygen microbubbles was also tried but this too gave rise to gas emboli as did the injection of oxygenated saline. Haemoglobin is much easier to oxygenate in the free form than when held in intact red cells. Amberson (1949) used a solution of free haemoglobin in Ringer's lactate to replace an animal's entire circulating volume and the animals behaved normally for several hours. However the free haemoglobin is taken up by the reticuloendothelial system and is also excreted in the urine so death resulted from hypoxia in 36h.

A technique of 'pervascular oxygenation' was described at the turn of the century (Magnus, 1902). Isolated organs were perfused with moist oxygen and basic organ functions continued for a limited time. In 1959 Sabiston kept an isolated heart beating for up to 8h with this technique.

All of these experiments concerned themselves with artificial oxygenation and ignored the need for removal of carbon dioxide.

Cross-circulation

The idea of using a 'donor' to support the vital function of a recipient circulation was conceived in the late nineteenth century. Fredericq (1890) diverted the circulation via glass tubes from the carotid artery of one animal to the carotid artery of another and was able to maintain cerebral function.

Cross-circulation for total body perfusion utilized what became known as the 'azygos principle'. It had initially been thought that flows comparable to the resting cardiac output were necessary to maintain vital centres during cardiopulmonary bypass, but Andreasen and Watson (1952) showed that dogs survived after clamping the venae cavae for up to 40 min provided the azygos vein was left open. The cardiac output was considerably reduced (about 10 ml kg^{-1} min^{-1}). Using this observation Cohen and Lillehei (1954) found that atrial operations could be tolerated but if ventriculotomy was to be performed, higher flows were found necessary – in the region of 20–40 ml kg^{-1} min^{-1}. This ability of the body to tolerate such low flows allowed the development of cardiac surgery supported by cross-circulation. Using a dual pump (arterial and venous) and a venous reservoir, Lillehei reported the use of this technique to repair intracardiac defects in 32 patients in 1955.

At the same time as conventional methods of cardiopulmonary bypass were being developed, various workers used preoxygenated blood held in a reservoir which was then slowly transfused to the recipient. However large volumes of blood were needed and the circulation could only be supported for a short period of time (and at low flow rates) by this method.

The lung as an oxygenator

The lung remains the ideal oxygenator since it also removes carbon dioxide and does not cause blood damage. In 1895 Jacobj used an isolated lung to oxygenate blood in various organ perfusion experiments and this technique was later developed to the point where it could be used as the oxygenator for whole body perfusion in animal experiments. Rather than use an isolated lung, Potts *et al.* (1952) cannulated the pulmonary circulation *in situ* and used this with a mechanical pump to perform cardiac operations on animals.

Mustard (1955) and other workers used animal lungs as oxygenators during human cardiac surgery after meticulous washing. However the system was complicated and not superior to artificial oxygenators being developed at the same time.

Right heart bypass was the natural extension of the isolated lung technique. This was used by Dodrill *et al.* (1953) to support the circulation while the right ventricle was excluded; this allowed open surgery to the right ventricular outflow tract. Combined right and left heart bypass using the lungs as an oxygenator was the next logical step and was apparently simple. However cannulation was sometimes difficult and achieving a balanced flow in the two circuits was also a problem. The problem of imbalance was resolved by Ross (1959) by allowing one reservoir to drain into the other if imbalance in venous drainage from each half of the circulation became too great.

Reduction of body temperature to 30°C allowed up to 10 min cardiac arrest, enough time to correct simple intracardiac lesions. Cooling below this temperature is liable to cause irreversible ventricular fibrillation. Combining hypothermia with cardiopulmonary perfusion overcame this problem and gave several advantages. Since the oxygen requirements of the body are reduced, the blood flow could be reduced. This in turn reduces collateral flow and gives a drier operative fields. Better oxygenation and less blood damage are also important benefits.

In dogs Bigelow (1950) showed that as their temperature was reduced, their oxygen requirement was reduced in an almost linear fashion. Drew (1958) combined profound hypothermia with combined right and left heart bypass using the patient's own lungs as the oxygenator. The patient was cooled to 15°C using right and left bypass allowing a much longer period of circulatory arrest. He reported seven cases with two deaths in which the circulatory arrest was up to 45 min. This time allowed much more complex lesions to be repaired especially as the operation was on a still bloodless heart. This was an important contribution at that time.

Oxygenators

Efficient gas exchange requires the exposure of blood to 'gas' over a large surface area to allow rapid equilibration between the two. Three basic types have been developed; bubble, film and membrane oxygenators.

Bubble oxygenators

Although the concept of oxygenation of blood by a continuous stream of oxygen bubbles was proposed at the turn of the century its use was initially confined to the intravenous injection of oxygen which led to pulmonary embolism and death. The use of a reservoir, bubble traps and defoaming agents to produce an essentially bubble-free arterial stream allowed the successful clinical use of bubble oxygenation (Clark *et al.*, 1950). The DeWall bubble oxygenator (DeWall *et al.*, 1956) used this principle. Oxygen was bubbled through blood which then flowed through a chamber coated with an antifoam compound. It then passed through a helical bubble trap and was filtered before being pumped to the patient. This oxygenator was intended to be easily sterilized and re-used. Eventually a disposable plastic version was developed which although only capable of low flow rates was efficient for about an hour.

The Rygg–Kyvsgaard 'bag' (Rygg and Kyvsgaard, 1956) took the same idea further. It combined the bubbling and settling chambers along with a reservoir in the same plastic 'bag'. Polythene sponges coated with an antifoam agent were used for debubbling. Flows of 3 l min^{-1} were delivered from the early designs and they remained relatively efficient for several hours.

The bubble concept is also used in 'foam' oxygenators but they differ from the above in that venous blood enters from the top of the oxygenator and flows over the large bubbles created by oxygen being bubbled in at the bottom. Arterialized blood then collects at the base of the oxygenator and is pumped to the patient.

Film oxygenators

The oxygenator developed by Gibbon which was used for the first successful open heart operations to be supported by a heart–lung machine was of this type. The principle is extremely simple. Blood is allowed to form a very thin film on a metal plate and is exposed to oxygen. This is not dissimilar to von Frey and Gruber's original concept of an oxygenator.

Gibbon's first oxygenator using the thin film principle utilized a vertical cylinder (Gibbon, 1937). The stream of venous blood was directed against the inner surface of the rapidly revolving vertical cylinder on to which it spreads in a thin film. This is then exposed to a mixture of 95% oxygen and 5% carbon dioxide at a gas flow of 5 l min^{-1}. Roller pumps were used on both arterial and venous sides of the oxygenator. There was no reservoir in the circuit but a membrane manometer was attached to a T-tube on the venous line: resting on this was a column of mercury which operated an electric switch. Whenever the venous return stopped because of the caval wall being sucked against the cannula the pressure in the manometer fell and the switch shut the pump off. As the level rose again the pump was similarly switched back on. Gibbon surrounded the blood tubing by a water bath to maintain a constant temperature during perfusion.

This system was capable of delivering 500 ml min^{-1} of oxygenated blood which was enough for his early experiments using cats in which he occluded the pulmonary artery for up to 25 min and supported the circulation with this system. Some of his animals survived for over a year. Gibbon felt at this time (1937) that his apparatus would not be capable of supporting the entire circulation of a man but that it might be able to be used as an assist device for the failing heart or be used in patients with massive pulmonary embolism until embolectomy could be performed.

The early film oxygenators were inefficient because diffusion of gas is limited to the superficial layer of the blood film. The efficiency can be increased by causing mixing of the blood and gas to occur. Gibbon's group used a screen of wire mesh to cause turbulence at the blood–gas interface and this greatly increased the efficiency of the oxygenator.

At the Mayo Clinic Kirlin's group built an oxygenator of the Gibbon screen type. It consisted of fourteen wire mesh screens, each 30 × 45 cm enclosed in a lucite case. Blood flowed on to the screens through a series of 0.006 mm slots; the gas flow was 10 l min^{-1} of oxygen the carbon dioxide flow being automatically varied according to the pH of the arterial blood leaving the oxygenator.

The efficiency of the film oxygenator could also be increased by increasing the surface area of the blood film.

Bjork (1948) realized that as oxygenation was almost instantaneous, blood only needed to be exposed to oxygen for a short time and that by rapid exchange of blood films efficient oxygenation could be achieved in relatively small apparatus.

He developed a film oxygenator comprising a number of vertical plates mounted on a central axle – he used 40 plates 13 cm in diameter arranged in groups of four along the axle. Each group was separated by a baffle in the floor of the oxygenator – this caused blood to mix and further improved efficiency.

Membrane oxygenators

As in the 'natural' lung the blood/gas interface is separated by a semi-permeable membrane (the alveolar capillary membrane), so in the membrane oxygenator this is replaced by a synthetic membrane. Separating the two media across a membrane has the advantage that a defoaming process is not needed and consequently blood trauma is reduced and longer bypass runs facilitated.

In his early dialysis experiments using a cellophane membrane Kolff (1944) observed that the venous blood became red. Later attempts to use this model as an oxygenator (rather than for dialysis) showed it to be a rather inefficient machine for gas exchange and only capable of arterializing blood at low flow rates (Kolff and Balzer, 1955).

Clowes and Neville used a multi-layered Teflon membrane oxygenator for human perfusion in 1957. However these oxygenators were rather bulky (the Clowes model had a membrane area of 25m^2) difficult to assemble and sterility was difficult to guarantee. Priming this large membrane lung was tedious and heat loss across it was marked.

It was an early hope that membrane oxygenation would allow the support of patients with acute reversible pulmonary insufficiency for days rather than hours and this was the main stimulus to further research.

The prevention of blood clotting proved to be a significant problem in the early membranes, probably because the surface area of foreign materials was very high, blood flow rather slow and inadequate doses of heparin were used.

Silicone proved to be the most permeable material to both oxygen and carbon dioxide and the early membranes were made by dip coating a nylon mesh in silicone rubber.

The membrane lung was introduced into clinical practice in the late 1960s. The Bramson model was one of the earliest: this consisted of fourteen 'cells' – each cell having a silicone rubber membrane across which diffusion occurred (Bramson *et al.*, 1965).

The use of tubular capillary membranes rather than flat membranes (with a welcome reduction in the size of the oxygenator) was first proposed by Bodell (Bodell, Head and Head, 1963). In this system gas can either flow in the capillaries with blood on the outside or vice versa. The latter method has been the most successful approach and has led to the development of very efficient hollow fibre membrane oxygenators.

Blood pumps

The development of efficient atraumatic blood pumping devices lagged behind advances being made in oxygenator technology. Many different types of pumping mechanism were used – centrifugal pumps, conical rollers, double rollers (like the DeBakey pump), Archimedian screw, worm screw, piston, diaphragm and ventricle type pumps.

In early experiments at the turn of the nineteenth century, Jacobj (1895) and other scientists used a rubber bladder compressed by a motor driven eccentric shaft. Diaphragm pumps using valved inlet and outlet ports were one of the simplest early pumping devices. Dale and Schuster (1928) are given credit for the development and use of this type of pump. It consisted of a water-filled chamber which was intermittently compressed by a plunger; this in turn compressed a blood-filled chamber and blood flow was directed in the appropriate direction by valves on the inlet and outlet ports. The main problem with this type of pump was its limited output, though Jongbloed (1949) used six such pumps in parallel to obtain flows in the range needed for total cardiopulmonary bypass.

The commonest type of pumping device seen on perfusion apparatus today is the roller pump. This is usually associated with DeBakey who in 1934 described this type of pump as an aid to rapid blood transfusion, though many other workers used similar pumps.

Roller pumps have the advantage of simplicity but the disadvantage of being relatively traumatic to blood because of the extreme shearing forces developed by the repeated compression of blood in relatively narrow bore tubing. The amount of blood trauma is directly related to the degree of 'occlusiveness' of the pump's rollers and by reducing the occluding pressure the degree of haemolysis can be reduced.

Conduct of bypass

In the early years of cardiopulmonary bypass there was considerable discussion as to whether venous blood should reach the pump-oxygenator as a result of gravity drainage or be assisted by a suction pump. Initially suction drainage was preferred as this presented a relatively constant flow of blood to the oxygenator (the film type of oxygenator in particular was much more efficient when presented with a constant flow of blood) but obstruction of the venous cannulae was a constant problem. Many elaborate devices to prevent venous occlusion by the caval walls such as automatic relays to stop the pump (Kantrowitz, Reiner and Abelson, 1950) and arteriovenous connections which could be opened to unblock the venous lines were used.

Direct gravity drainage into the oxygenator had the advantage that it was simple and required little priming volume. However constant flow was difficult to ensure and this reduced the efficiency of the oxygenator. The problem was solved by using gravity drainage into a reservoir – the level of which could be varied to improve drainage – which then fed the oxygenator (Paneth *et al.*, 1957). A pump was sometimes used to transfer blood from the reservoir to the oxygenator.

Arterial cannulation was also the subject of much controversy in the developing specialty. The limit to arterial return became not the blood pumps but the size of the arterial cannula which in turn was controlled by the size of the vessel to be intubated. Small cannulae resulted in high flow velocities and more haemolysis (Senning, 1952), so metal cannulae were preferred to the plastics available at the time because the ratio of internal to external diameter was high and thus for any given flow, velocity could be reduced.

In animal experiments the femoral, carotid and subclavian arteries had all been used for arterial cannulation. The subclavian approach fell out of favour when median sternotomy became the incision of choice. Many surgeons were initially worried that the direction of flow in the aorta was important and that inflow from the distal half of the body would not generate sufficient pressure to perfuse the cerebral and coronary vessels but femoral cannulation soon became the standard approach – though Kirklin felt that the external iliac artery was a better choice because it could accommodate a larger cannula.

Special cannulae which could be used conveniently for direct aortic cannulation were developed though it was many years before this became the standard route.

In the early days of bypass surgery the heart–lung machine was primed with fresh heparinized blood. Often large amounts were used and this caused an enormous strain on the blood banks. Postoperative bleeding was common and accentuated this problem. Controversy surrounded the amount of heparin required during the perfusion and the amount of protamine needed to neutralize it. The use of haemodilution has greatly simplified open heart surgery.

Clinical use

Possibly the first attempt to use cardiopulmonary bypass in the clinical setting was in Minneapolis in 1951. Dennis *et al.*, 1951 had developed a Gibbon type oxygenator in a series of experiments in dogs. The problems in development were immense. They were able to produce a dry operating field but after only 30 min of perfusion 50% of the serum proteins had been lost, the platelet count had fallen by two-thirds and there was a marked metabolic acidosis. Fatal gastrointestinal haemorrhage often occurred in their animals. It was not until they realized that the perfusion apparatus was contaminated by *Escherichia coli* and that this was responsible for their problems were they able to progress by sterilizing the equipment in 3% formaldehyde for 12h. The system then had to be rinsed with 30 litres of saline before use. The group eventually modified Gibbon's rotating cylinder and used slowly rotating screen discs on to which blood was laid in fine jets. The 38 cm discs rotated 54 times per minute and could raise the oxygen saturation of a pint of blood from 45% to 95%. By using several similar discs mounted together on a shaft (after the method described by Bjork) they were able to use the system to operate on an adult patient.

On 5 April 1951, Dr R.L. Varco operated on a patient with a preoperative diagnosis of Lutembacher's syndrome (secundum atrial septal defect,) ASD, with mitral stenosis) using this system. The patient had 'pulmonary oedema and such cardiac enlargement as to completely collapse the left lung'. Bypass was set up between bicaval stainless steel cannulae and the right subclavian artery. Unfortunately the return of blood to the right atrium via the Thebesian veins was 250 ml min^{-1} and the lesion proved to be an ostium primum defect. An attempt was made to close it directly with interrupted sutures. Large amounts of citrated bank blood had to be added to maintain the circulation and it was felt that this caused the subsequent heart failure. The patient could not be weaned from bypass.