Continuous Ambulatory Peritoneal Dialysis

EDITED BY

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Foreword

The renal physicians and transplant surgeons who learned their trade in the early 1960's carried on despite the most dismal results. The first report of the Registry of the European Dialysis and Transplant Association recorded a 1 year survival rate for regular haemodialysis below 50%. At the first meeting of British Transplant groups in 1964, most reported up to 20 transplants without a single long-term survivor. When challenged whether our activities were worthwhile we could only reply that, to most of our patients, the only alternative was infinitely less desirable. Perhaps the fact that we could justify poor results by that defence, and by the shortage of resources, explains how slowly we learned. For the next 15 years most centres poisoned their patients by making dialysis fluid from untreated water, to contain unphysiological concentrations of sodium and magnesium, giving unnecessary vitamin A and administering too many drugs in doses that took little account of the effects of renal failure. We exposed them to the risks of haemolysis, air embolism, copper poisoning or electrocution and repeatedly attributed to psychological stress the organic complications of renal failure and its treatment.

When Continuous Ambulatory Peritoneal Dialysis (CAPD) came on the scene, death was no longer the alternative, except in a few countries like Britain where an administrative quirk made it available to patients who were precluded from haemodialysis by cost control. It had to achieve results as good as those from techniques that had evolved over nearly 20 years. And it had to do so fast for its expansion was phenomenal. In absolute numbers, its use expanded in Britain almost ten times as fast as haemodialysis in its early years. So the learning curve has perforce been much steeper.

This has been helped by the efforts of companies who rightly judged that their success depended on the education of doctors and nurses in the use of CAPD. There has been a rapid succession of international meetings and already CAPD has spawned its own journal and its own international society with attendance at its first meeting approaching four figures. Indeed the out-pouring of scientific articles has caused intellectual indigestion and I, for one, have given up the struggle to file and index even the most important. That is a good moment in the history of a subject for the first definitive textbook. Already the subject calls for a multi-author text.

It is therefore a pleasure to introduce a book that provides both a summary of our scientific knowledge in this mushrooming subject and a practical guide for the doctor who performs the technique. It is a particular pleasure to find among the authors many who have led the field: Dr Karl Nolph who set up the first large programme in America and convinced the world that it worked; Dr Dimitrios Oreopoulos who introduced the plastic bag that solved many of the early problems; Dr Charles Mion, whose experience of CAPD and its predecessor IPD, is still unrivalled; Professor Peter Farrell who achieved the rare feat of supervising a national clinical programme from a department of bioengineering; Dr Jonas Bergström who has brought to the problem of nutrition in CAPD a life-time of experience in the other nutritional problems of renal failure, to mention a few. The editor's personal enthusiasm for CAPD and his success in its use has played a major part in the expansion of the British programme.

I commiserate with these authors because knowledge of CAPD is bound to go on expanding and

they are now committed to revising their chapters on an almost continuous basis. Their task will be eased by a little feedback from the readers. I have always found comments from readers on what I have written in textbooks the most valuable source of criticism. It is particularly helpful to have your views challenged by those who quote evidence from the literature or their own experience for alternative viewpoints. Even if I do not change my story in the next edition, I at least defend my original statement more vigorously. So do not be shy; if you do not like, or understand, what you read, get out your dictaphone, and send a copy to the editor!

London, 1985 *David N S Kerr*

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Preface

Although the concept of peritoneal dialysis has been with us for many decades, its use in the management of patients in end-stage renal failure was of a limited nature until the introduction of continuous ambulatory peritoneal dialysis in 1976. Since then interest in peritoneal dialysis has increased tremendously with about 10% of the world's dialysis population being managed by CAPD.

This book is meant to provide an overview of the state of art of CAPD, 10 years since Popovich and Moncrief first introduced the concept. Over this period the rapid and largely successful deployment of CAPD has not been without its problems. This is partly related to our lack of total understanding of the peritoneum and its behaviour. Yet new ideas and developments are being reported at a rapid rate in the medical literature. The book is an attempt to condense this knowledge; the various chapters in the book are extensive and provide comprehensive and up-to-date reviews of the subject with practical guidelines for various techniques, procedures and management problems in CAPD.

I feel fortunate to have been involved with CAPD since its inception in the UK in 1978–1979 and to have come into contact with leading workers in the field, some of whom have so kindly contributed to this book. These authors have been actively adding to the knowledge in their respective topics for many years.

Although I have made efforts at editing out overlap and repetitions between chapters, some is inevitable; I have felt that to allow authors latitude to fully express all the issues related to their topics will give the reader different perspectives of aspects of CAPD especially in situations when no single theory, technique or management procedure is universally accepted. Whilst every effort has been made to provide correct and up-to-date information, I take no responsibility for any misinformation.

It is my earnest hope that this book will serve as a reference text on CAPD to nephrologists, physiologists, pharmacologists, biomedical engineers, nurses and social workers interested in the field.

My sincere thanks go to the contributors, to Miss P. Mavani, Mrs G. Russell and my secretary, Mrs S. Jenkins, for their tireless efforts at typing manuscripts and edited versions, and to various national and international bodies for providing data.

August 1985

R. Gokal

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Historical development and clinical use of continuous ambulatory peritoneal dialysis

Continuous ambulatory peritoneal dialysis (CAPD) has now become an established form of renal replacement therapy. Its use throughout the world is gradually increasing and has provided a means of managing some patients who would otherwise have been denied treatment. The current state of the art has been a culmination of the painstaking efforts and ingenuity of several innovative pioneers in this field over the last two centuries. This chapter describes these historical developments leading up to CAPD as it is practised today in most countries where dialysis is undertaken.

HISTORICAL REVIEW OF PERITONEAL DIALYSIS

Early studies of peritoneal anatomy

Probably the first observers of the peritoneal cavity were the early morticians in Egypt, who delicately prepared the remains of influential Egyptians to ensure that the body would remain uncorrupted for eternity.[1] Cunningham[2] reports that 'the Egyptians recorded, in the Ebers papyrus, written about 3000 BC, the peritoneal cavity to be a definite entity in which the viscera were somehow suspended'. In conjunction with these anatomical studies these Egyptians also attempted to treat impaired renal function by inducing diarrhoea with the use of purgatives or forced diuresis using beer. They were thus aware of oedema and understood the effects of diuresis. In Greek times, Galen, a physician, made detailed descriptions of the abdomen while treating injuries of gladiators. He provided precise details of the peritoneal cavity and the peritoneum.[1]

The first descriptions of the 'therapeutic' use of the peritoneal cavity were made in the eighteenth century. Christopher Warrick, who presented his findings at a meeting of the Royal Society in 1744, managed a female patient aged 50 with severe ascites by infusing a mixture of one-half Bristol water and one-half Claret into the peritoneal cavity after draining the ascites.[3] She miraculously recovered from the ensuing syncopy and pain and underwent two further such 'exchanges'. Over several weeks the ascites and oedema resolved! In the same year Rev. Stephen Hales, a curate of the village of Teddington, England, described a method of conveying liquors into the abdomen during the operation of tapping fluid from it.[4] His technique, a modification of Warwick, entailed introducing two trocars, one on each side of the abdomen, allowing the liquor to flow in and out of the abdomen. These novel approaches are almost certainly the predecessors of subsequent attempts to enter the peritoneal cavity.

Early studies of physiology of peritoneum

Several attempts to use the peritoneal cavity were reported in the late nineteenth century. Wegener in 1877, found that hypertonic solutions of sugar, salt or glycerine increased in volume when injected into the peritoneal cavity of a dog.[5] Starling and Tubby in 1894, showed that hypertonic intraperitoneal solutions would increase in volume whilst hypotonic solutions would decrease in volume.[6] They studied the absorption of such substances as indigo, carmine and methylene blue from the peritoneal cavity and concluded that solute exchange was primarily between solutions and blood; the exchange with lymph was negligible. Cunningham in 1920 showed the complete absorption

of a 10% dextrose solution from the rat peritoneal cavity in about 12 hours and concluded that most absorption could be explained on the basis of 'the known physical laws of osmosis and diffusion'.[7]

Spurred on by these interesting physiological studies and the report of Abel in 1913 on 'vivi diffusion' (or haemodialysis) in animals,[8] Putnam published his work on dogs, characterising the peritoneum as a dialysing membrane.[9] His studies were extensive, looking at fluid removal (ultrafiltration), and exchange of chloride, urea, dextrose and protein concentrations at various intervals of time. He concluded that, 'under certain circumstances, fluids in the peritoneal cavity can come into an apparently complete osmotic equilibrium with the plasma', and that 'the speed of diffusion of different molecules through the peritoneum appeared to vary with their respective sizes'. He also pointed out that 'changes in volume reflected the osmotic forces at work'. His work on the transfer of colloids and crystalloids from peritoneal cavity to the blood and vice versa were fundamental in establishing the principles of solute transport and ultrafiltration which are still true to this day. These studies were further amplified by Engel in 1927.[10] He observed that the clearance of solutes was proportional to their molecular size and solution pH, and that high flow rate maximised the transfer of solutes which also depended on peritoneal surface area and blood flow.

Early experiences of PD in uraemia: 1923–1960

George Ganter, working in Germany was the first person to evaluate peritoneal dialysis in the management of uraemia in animals and man.[11] In 1923 he performed peritoneal dialysis in rabbits and guinea-pigs with ligated ureters. Utilising 2–4 hour exchanges there was almost complete equilibration of non-protein nitrogen in the dialysate with that in the blood. There appeared to be some clinical improvement in the animals. Ganter used this technique to treat an uraemic woman suffering from chronic nephritis. He introduced 1.5 l salt solution through a needle in the peritoneal cavity. There was transient improvement in symptoms when the solution was removed, but the patient subsequently died. From his experience with the use of peritoneal dialysis he was able to elicit several features upon which he based his recommendations: the use of 1–1.5 l per exchange with close monitoring of the equilibration time; the use of hypertonic solutions with an anaesthetic to minimise pain; and continuous lavage for cases of poisoning but a dwell phase between exchanges for uraemia. He postulated that with improvements this procedure could become an innovative and useful form of renal care.

A number of other reports subsequently confirmed the usefulness of peritoneal dialysis in uraemia.[12–16] Odel et al reviewed the literature between 1923 and 1948 and reported that 101 patients had received peritoneal dialysis over this period. Of these 63 had reversible causes, 32 irreversible, and in 2 the diagnosis was uncertain.[17] There was recovery in 32 of the cases with reversible causes; death in 40 cases was predominantly related to uraemia, pulmonary oedema and peritonitis. Derot et al reported the first successful experience in acute renal failure with 9 out of 10 survivors.[18] Following the work of Grollman et al,[20] who demonstrated the use of intermittent peritoneal dialysis in nephrectomised dogs, Legrain & Merrill[19] used this form of dialysis in three patients; in one of them three procedures were performed in a 2 week period. They stressed frequent dialysis, dietary salt and protein restriction and avoidance of infection.

Over this early period, up to 1960, the methods and techniques involved were ingenious improvisations. Catheters were made from tubings available on the ward and included gall-bladder trocars,[15] rubber catheters,[14] whistle tip catheters and stainless steel sump-drains. In the early fifties, polyvinylchloride[18,19] and polyethylene plastic tubes[20] were employed to gain peritoneal access but were troubled with kinking and blockage. Maxwell et al[21] described a nylon catheter with small perforations at the curved distal end. This catheter became commercially available and widely used subsequently.

The techniques varied from continuous flow (two catheters used)[14,18,19] or intermittent (one catheter with tip in pelvis).[10,13,21,22] The latter had the advantages of fewer infections and leaks, and in the fifties became the accepted technique. The fluid composition varied considerably from normal

saline to 5% dextrose. The acidosis was corrected by use of lactate.[16] Commercial solutions became available in 1959.[28] Peritoneal dialysis efficiency and clearances were first worked out by Boen.[22]

These changes and improvements, though important, did not allow the use of peritoneal dialysis on a long-term bases for the management of patients in end-stage renal failure. Further advances were primarily related to catheter improvements which made long-term therapy possible.

Intermittent chronic peritoneal dialysis (1960 onwards)

In the early sixties various devices were tried to achieve easy and frequent access into the peritoneal cavity. These included the Seattle Teflon and silicone rubber tubes[23] and conduits[24,25] but failed because of peritonitis and adhesion formation. Boen and colleagues[26] developed the repeated puncture technique with automatic cycling machines. This enabled complete freedom between dialysis sessions and this technique could be adapted for home use. Tenckoff et al[27] carried this out in a patient for 3 years entailing 380 catheter punctures. There was also a lower peritonitis rate. However, this procedure could not be used on a large scale as it was too time consuming.

A major advance was brought about by Palmer et al,[28] Gutch[29] and McDonald et al[30] who all utilised silicone rubber catheters, which incorporated perforations at the distal end, and a triflanged step or a Teflon velour skirt for seating the tube in the deep fascia and peritoneum. However it was not until Tenckhoff's design of the indwelling silicone rubber catheter, which had two Dacron cuffs[31] that intermittent peritoneal dialysis became accepted as a long-term therapy for renal failure patients (Ch. 6). Using automated machines and this catheter, a large experience was built up in the Seattle area[32] with reports of prolonged dialysis of over 4 years.[33] Similar experience was reported by Oreopoulos in 1975[34] and subsequently by centres in Europe.[35,36]

Long-term therapy beyond 4 years was not often achieved with a cumulative technique survival of 27% at 3 years[37] in the Seattle group of patients. Inadequate dialysis was one reason for conversion to haemodialysis, as was repeated peritonitis. For these reasons, haemodialysis remained the cornerstone of dialysis therapy and for PD to challenge this position a major rethink was necessary. This came about in the mid seventies.

CAPD

The concept of CAPD had its origin in Austen, Texas, USA, when in 1975 Dr R. Popovich and Dr J. Moncrief (Fig. 1.1) were discussing ways to dialyse a patient who could not receive HD or IPD. This 'brainstorming' session induced Dr Popovich,

Fig. 1.1 The father-figures of CAPD—Dr J. Moncrief (left) and Dr R. Popovich (right). (Photograph kindly provided by Dr Popovich.)

a biomedical engineer with knowledge of membrane kinetics to theorise the use of long dwell cycles to achieve adequate removal of uraemic waste products to sustain life (Ch. 3). Based on mathematical calculations, which suggested that adequate control could be achieved on five daily exchanges of 2 l, 7 days a week, clinically Moncrief tried this in a patient and found that the results matched the theoretical ones. Later this was tried on a few more patients with equally satisfactory results. Ironically their first description and account of their clinical experiences was not accepted for presentation at the American Society for

Artificial Internal Organs[38] (Fig. 1.2). It was initially called 'a portable/wearable equilibrium dialysis technique'. This group described the theoretical mass transfer characteristics for this procedure as well as some preliminary, somewhat disappointing clinical experience in three patients.[39] Notwithstanding this discouragement a major cooperative study was begun in 1977 supported by the National Institute of Health. These included clinical studies at the Austin Diagnostic Clinic, Texas (Dr Moncrief) and the University of Missouri (Dr K. Nolph), with the biomedical engineering support of the University of Texas (Dr Popovich). Their joint experience in nine patients (duration of CAPD 5–26 weeks) was described in 1976[40] and the name of the technique was changed to continuous ambulatory peritoneal dialysis.

THE DEFINITION OF A NOVEL PORTABLE/WEARABLE EQUILIBRIUM PERITONEAL DIALYSIS TECHNIQUE.
Robert P. Popovich, Jack W. Moncrief, Jonathan F. Decherd, John B. Bomar* and W. Keith Pyle.*
Depts. Chem. Engr. and Biomed Engr., The Univ. of Texas and Austin Diag. Clin., Austin, Texas.

An analysis will be presented which predicts that acceptable blood metabolite levels will result if 10 liters of dialysate per day are allowed to continuously equilibrate with body fluids. Accordingly, a portable/wearable dialysis procedure based upon equilibrium-intermittent peritoneal dialysis has been defined. Two liters of standard hypertonic dialysate fluid are infused peritoneally via a Tenckhoff catheter and allowed to equilibrate 5 hours while the patient conducts his normal activities. The dialysate is then drained and replaced with the procedure being repeated five times per day.

In a preliminary clinical study metabolite equilibration between blood and dialysate was achieved for BUN and creatinine but not for vitamin B-12. Steady state metabolite levels for BUN and creatinine were 40 and 9.5 mg% respectively. The patient was maintained 5 months with the new procedure with excellent clinical results followed by a successful transplant.

It is concluded that a new portable/wearable dialysis procedure has been defined. The technique does not require blood access and results in steady, low blood metabolite levels: middle molecule removal greatly exceeds that of conventional techniques.

Fig. 1.2 The abstract of the first description of CAPD by the pioneers Dr Popovich and Dr Moncrief, as it appeared in the Abstract book of the American Society of Artificial Organs Meeting of 1976.[38]

The main advantages of this new technique were good steady state biochemical control, more liberal dietary and fluid intakes than haemodialysis, improvement in anaemia and wellbeing of the patients, and freedom from machines which allowed patients to travel long distances. However, these studies utilised peritoneal dialysis solutions in bottles. Connections and disconnections of tubing and bottles to the Tenckhoff catheter were required with each exchange and chances of contamination were high. Hence, not only was the technique cumbersome and time consuming, but was complicated by a high incidence of peritonitis (1 episode/every 10 patient week). In addition obligatory protein losses in the dialysate amounted to 13–18 g/day.[40]

In September 1977, the team from Toronto Western Hospital, Canada, led by Dr Oreopoulos, started their first patient on CAPD using a novel modification of the above technique, with PD fluid in polyvinylchloride (PVC) bags. Following instillation of the fluid, the plastic bag, still connected to the administration set, was rolled up and carried under clothing without much difficulty. After a dwell period of (4–8 h) the fluid was allowed to drain into the same bag under the 'force of gravity', without disconnecting the tube from the Tenckhoff catheter[41] (Fig. 1.3). The technique details were first presented in January 1978, at the 11th Annual Contractors Conference of the Artificial Kidney Programme Institutes of Arthritis, Metabolism and Digestive Disease in Bethesda, USA.[42] The Oreopoulos modification made CAPD easier to perform, and decreased (but did not eliminate) the rather high incidence of peritonitis (1 episode/10 patient weeks to 1 episode/8 patient months). This represented a major advance and the use of CAPD increased in an explosive way. By June 1980, 115 patients were managed on CAPD at the Toronto Western Hospital.[43]

In September 1978, the Food and Drug Administration approved sale of peritoneal dialysis solutions in plastic bags in the United States; this led to many centres developing CAPD programmes.[44] Another major step in the growth of CAPD in the USA was the announcement by the Health Care Financing Administration (Medicare) in October 1979, that CAPD was reimbursable and an accepted alternative to chronic haemodialysis. The growth

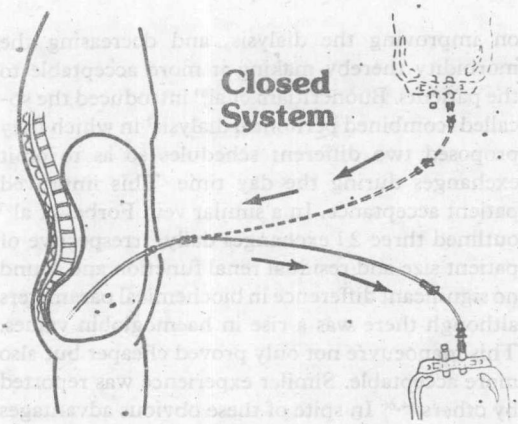

Fig. 1.3 The CAPD system as devised by Dr Oreopoulos[41] entails the drainage of fresh PD fluid into the peritoneal cavity under the influence of gravity (dotted bag and transfer set). The empty bag in continuity with the transfer set is then wrapped and held adjacent to the body or in a pocket. At the end of a dwell period of 4–8 h the same bag is lowered, the clamp undone and fluid drained by gravity into the empty bag (full lines and bag) which when full is exchanged for a new one using a strict non-touch technique. This is thus a 'closed system'. (Reproduced with permission—Travenol®.)

thereafter has been exponential. By July 1980 over 1700 patients were treated in 190 centres.[45]

This growth was mirrored in other leading Western nations (Table 1.1). With this rapid increase a number of groups in Canada,[43,51] Europe,[48,52] UK[53] and Australia[56] undertook programmes of clinical evaluation of the technique. All groups found CAPD to have many advantages when compared to IPD and even haemodialysis although the major problem still was that of peritonitis, leading to a high technique failure rate.

Evolution of CAPD technique

The CAPD technique, as initially proposed by Popovich and Moncrief, entailed four exchanges of 2 l volumes, using a combination of three 1.36 g and one 3.8 g glucose to produce a 10 l dialysate volume over a 24 h period. This necessitated 4–8-h dwell periods adjusted to fit into the patients daily routine. The initial use of glass bottles resulted in an unacceptable peritonitis rate but with the introduction of the PVC bags there was a dramatic improvement.

Table 1.1 Number of patients in individual countries on CAPD by July 1980, also expressed as a % of total dialysis population

Country	*No. of CAPD patients*	*% of dialysis population*	*Reference*
Australia	102	—	46
Belgium	99	12	47
France	254	3.2	48
Italy	240	2	49
United Kingdom	230	10	50

The basic CAPD system, which to this day remains unchanged consists of the PVC bag containing 0.5–3 l peritoneal dialysis fluid, a transfer set and Tenckhoff catheter (Fig. 1.4). The connection between the bag and transfer set (Fig. 1.4, Site 1) is broken four times a day, and the exchange procedure transferring the set from the spent bag to the new bag has to be performed using a strict sterile non-touch technique (Ch. 7). Various devices (connectors) have been developed to minimise the risk of contamination (Ch. 5), yet this site remains the major source of peritonitis.[55] Initially 'spike' connectors, at Site 1 and 2, led to accidental catheter and bag disconnections. In addition bag leaks and fluid leaks from defective materials used in the manufacture of connectors[56] plagued the procedure and maintained a high

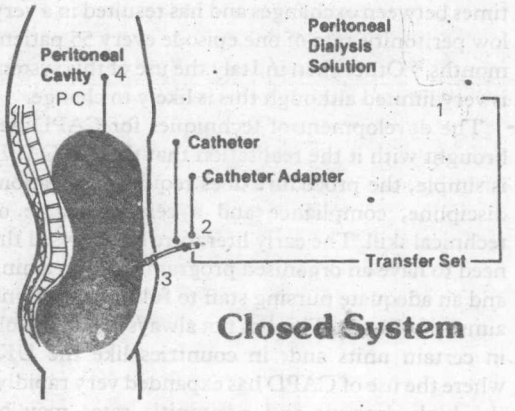

Fig. 1.4 The CAPD system. 1, Denotes connection between transfer set and PD fluid bag. This connection is broken 3–4 times a day to effect exchanges. 2, Connection between Tenckhoff catheter and transfer set, incorporating a titanium connector. This connection is undone every 2–4 months for transfer set changes. 3, Exit site. 4, Peritoneal cavity (PC). (Reproduced with permission—Travenol®.)

peritonitis rate. The connections between Tenckhoff catheter and transfer set (Site 2) was improved substantially by the introduction of a luer-locking titanium peritoneal catheter adaptor in 1979[44] and this led to a further reduction in the peritonitis rate. From the initially weekly transfer set changes advocated by Oreopoulos,[41] monthly set changes were introduced early in 1979:[42] improvements in these with newer materials has led to set changes being performed at 2–6 monthly intervals.

An inherent problem with this technique is that having made a connection of transfer set to a new bag, fluid is drained into the peritoneal cavity. If the exchange procedure has led to a contamination of the connector, micro-organism will pass with the fluid into the peritoneal cavity. The Italian Y set connector system utilising a closed double bag, overcomes this inherent problem.[57,58] This CAPD system includes two bags, one containing the peritoneal dialysis fluid whilst the other is empty. They are connected by a Y-tubing with a sterile capped needle (Ch. 5). After the connections are made, the dialysate from the peritoneal cavity is drained into the empty bag followed by drainage of fresh fluid from the other bag into the peritoneal cavity. The two bag system is then disconnected and the Y piece is filled with chlorhexidine. This system thus enables the patient to be bag-free at all times between exchanges and has resulted in a very low peritonitis rate of one episode every 55 patient months.[59] Other than in Italy the use of this system is very limited although this is likely to change.

The development of techniques for CAPD has brought with it the realisation that though CAPD is simple, the procedure does require motivation, discipline, compliance and a certain degree of technical skill. The early literature emphasised the need to have an organised programme for training and an adequate nursing staff to fulfil the teaching aims[60–62] (Ch. 7). This has not always been possible in certain units and, in countries like the UK, where the use of CAPD has expanded very rapidly, the high dropout and peritonitis rates may be related to limited facilities and staff.[63]

Recent developments

Although the technique for CAPD has not changed substantially, recent innovations have had an effect on improving the dialysis, and decreasing the morbidity thereby making it more acceptable to the patients. Buoncritiani et al[64] introduced the so-called 'combined peritoneal dialysis' in which they proposed two different schedules so as to omit exchanges during the day time. This improved patient acceptance. In a similar vein Forbes et al[65] outlined three 2 l exchanges daily, irrespective of patient size and residual renal function and found no significant difference in biochemical parameters although there was a rise in haemoglobin values. This manoeuvre not only proved cheaper but also more acceptable. Similar experience was reported by others.[44,66] In spite of these obvious advantages there is the real danger that some patients may well be underdialysed on this regime or require a higher number of hypertonic exchanges which potentially could be detrimental to the peritoneum. Dialysis prescription is vitally dependent on patient age, dietary intake and residual renal function and regimes need to be individually tailored to the patient's requirements.

One of the advantages of reducing the number of daily exchanges is the decrease in peritonitis rate.[67] In order to achieve adequate dialysis and also decrease the exchanges, it is necessary to increase instillation volumes. Twardowski et al[68] first described that 2.5 l exchanges were well tolerated by 13 of 16 patients studied in 1981, and showed adequate ultrafiltration and clearances. The major determinant of the patient's tolerance of large volumes appeared to be the respiratory vital capacity which was significantly lower in patients not able to tolerate the 2.5 l. In a subsequent report by the same group, experience to 3 l exchange was reported in 18 stable CAPD patients.[68] Tolerance of large volumes was correlated with forced vital capacity, intra-abdominal pressure and forced expiratory volume at 1 s in supine, sitting and upright positions. Three litre exchanges were tolerated by a smaller proportion of patients than was found for 2.5 l and forced vital capacity in the supine position seemed the most sensitive indicator of tolerance of large volumes of fluid. Nine of the 18 patients managed the 3 l volume. In the experience from Toronto, 30% of patients starting CAPD were able to tolerate 3 l exchanges[70] without increase in dialysate protein losses. This group also reported less frequent use

of hypertonic exchanges suggesting that higher volumes may improve ultrafiltration due to the maintenance of a concentration gradient over a long dwell time with higher dialysate volumes.[71] It is advisable when initiating CAPD therapy in a patient to ascertain tolerance of the various volumes of fluid, as up to 50% may comfortably be able to take greater than 2 l. However over long-term usage there may be the risk of herniation.

Continuous cyclic peritoneal dialysis (CCPD) was a further development, which retained the physiological advantages of CAPD but eliminated diurnal exchanges, again making it more convenient for the patient. It was first described by Diaz-Buxo and colleagues.[72] The technique requires a peritoneal dialysis cycler with a timer to allow dwell periods of 3–4 h. Prior to retiring at night the patient's catheter is connected to the cycler which is programmed to deliver three exchanges of 2 l each. After the last drainage, an additional 2 l are infused into the peritoneal cavity and allowed to dwell throughout the day. The prolonged diurnal cycle usually entails use of the 3.8% glucose solution. This therapy does provide adequate clearances and ultrafiltration, an uninterrupted day of activities and decreases peritonitis. The main disadvantage of CCPD is the need for a machine. In spite of this CCPD has not caught on as a major form of dialysis therapy although it may be suitable for some patients.

Clinical results

Control of uraemia

CAPD unquestionably works and produces good biochemical control. Because it is a continuous therapy, it provides steady state blood values for electrolytes and nitrogenous waste products. The precise blood levels will depend on the residual kidney function, the daily dialysate volume and the rate of production of the waste products which reflects, in part, dietary intake. Assuming that the latter is constant, one can predict the blood level based on residual renal functions and dialysate volume. Blood urea and creatine levels of 20–30 mmol/l and 1000 μmol/l respectively are readily achieved and acceptable.

The signs and symptoms associated with high efficiency intermittent procedure like HD are infrequent in CAPD patients. This is particularly noticeable in patients transferred from HD to CAPD who note the increased sense of well-being and the improved appetite. Nausea, anorexia, headaches, somnulance and postdialysis lethargy and uncommon in CAPD patients.

Sodium and water balance

Relatively large amounts of sodium and water can be removed with the use of hypertonic glucose dialysate. Rapid ultrafiltration will cause movements of sodium free water from blood into the peritoneal cavity.[73] Hypernatraemia will occur should this rate of ultrafiltration persist. However the prolonged dwell time of CAPD allows near equilibration of sodium concentration in the blood and dialysate.[74] Hence if 2 l of ultrafiltrate is produced daily, a negative sodium balance could approach 280 mmol. In practice the amount removed is usually a lot less, and dependent on the dialysis fluid sodium concentration, and use of the 3.8% glucose concentration. Oreopoulos[75] calculated a removal of about 140 mmol sodium/day using 3 exchanges of 1.36 and 1 of 3.8% solutions containing a sodium concentration of 132 mmol/l; Nolph measured this sodium loss to be about 175 mmol/day.[76] Ultrafiltration with glucose occurs within the first 2–4 h after which the dialysate becomes virtually isotonic. Approximately 800–1000 ml of ultrafiltrate occurs with a 3.8% glucose solution and 200–400 ml with a 1.36% solution within this time period (Fig. 1.5). A gradual fall in the intra-abdominal volume then occurs. Whereas, the liberal use of 3.8% glucose solution can lead to removal of enough salt and water to allow free access of these to the patient the practice is certainly unwise. Frequent use of hypertonic solutions may well have a detrimental effect on the peritoneum although absolute proof of this is lacking (Ch. 3); however, fluid and salt restriction where necessary is judicious.

The ease with which sodium and water are removed has a major bearing on the control of hypertension and symptoms of hypotension (Ch. 11).

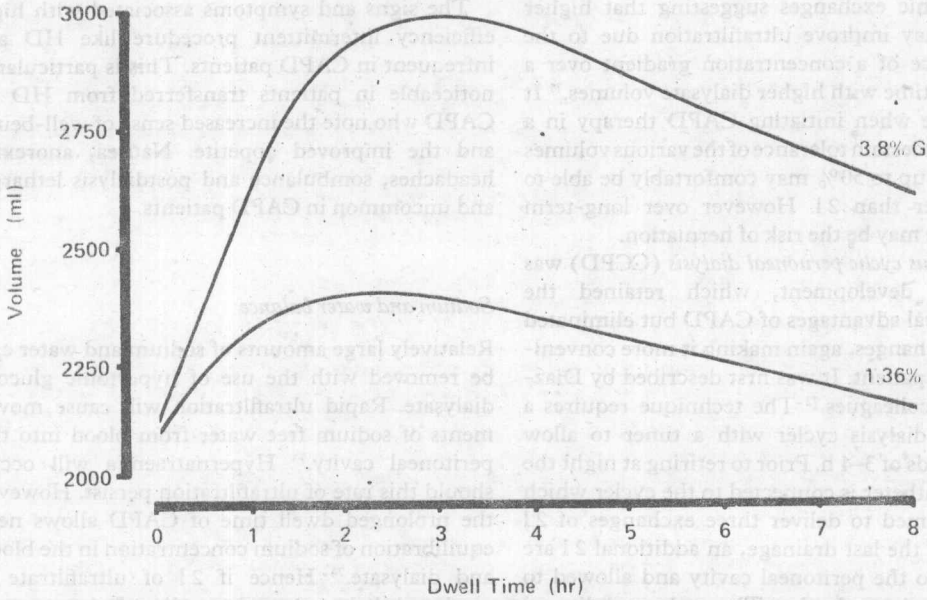

Fig. 1.5 Intraperitoneal volume changes with prolonged dwell times in CAPD using 1.36% and 3.8% glucose solutions. Data derived from personal observations[82] and those from literature.

Potassium and bicarbonate control

Most PD solutions contain no potassium. Patients on these solutions would therefore lose 25–30 mmol/day via the dialysate. This amount is exceeded by the normal potassium intake of 70–80 mmol/day. In spite of this most patients have a normal serum level, and hyperkalaemia is exceedingly uncommon. This anomaly can only be explained by an increased excretion of potassium in the stools[76,77] as it is unlikely that the additional amount is retained in the cells.

With a PD fluid lactate of 35 mmol/l, most patients are in a negative peritoneal bicarbonate balance and serum bicarbonate levels are slightly below normal and CAPD patients display a chronic mild metabolic acidosis.[78] Teehan et al[79] studied this problem in some detail and examined the major determinants of acid–base balance, namely lactate uptake (or base gain), dialysate bicarbonate and base equivalent (organic anion) loss, metabolic hydrogen ion generation and net renal acid excretion. In patients with no residual renal function, their results showed that lactate uptake from the PD fluid was efficient (70%) but was often exceeded by the sum of dialysate bicarbonate loss and hydrogen ion generation. Since metabolic hydrogen ion generation was normal (< 1 mmol/kg/day) and organic anion loss was small (< 4 mmol/day) lactate flux and dialysate bicarbonate loss were the major factors determining acid–base balance. This negative balance could be corrected by an increase in PD fluid lactate concentration. Nolph et al[80] in a multi-centre study have evaluated such a solution containing 40 mmol/l lactate (as opposed to 35 mmol/l) and shown a rise in serum bicarbonate from 23.8–27 mmol/l.

Monitoring of biochemical parameters

Although all biochemical monitoring is based on blood samples, it is possible to utilise the long overnight-dwell dialysate for these measurements.[74,81] The dialysate/plasma (D/P) equilibration curves obtained during 6 h dwell time show almost total equilibration for small molecular weight substances, like urea and creatinine, whereas phosphate being a larger molecule takes longer to achieve a D/P ratio of 1 (Fig. 1.6).[82]