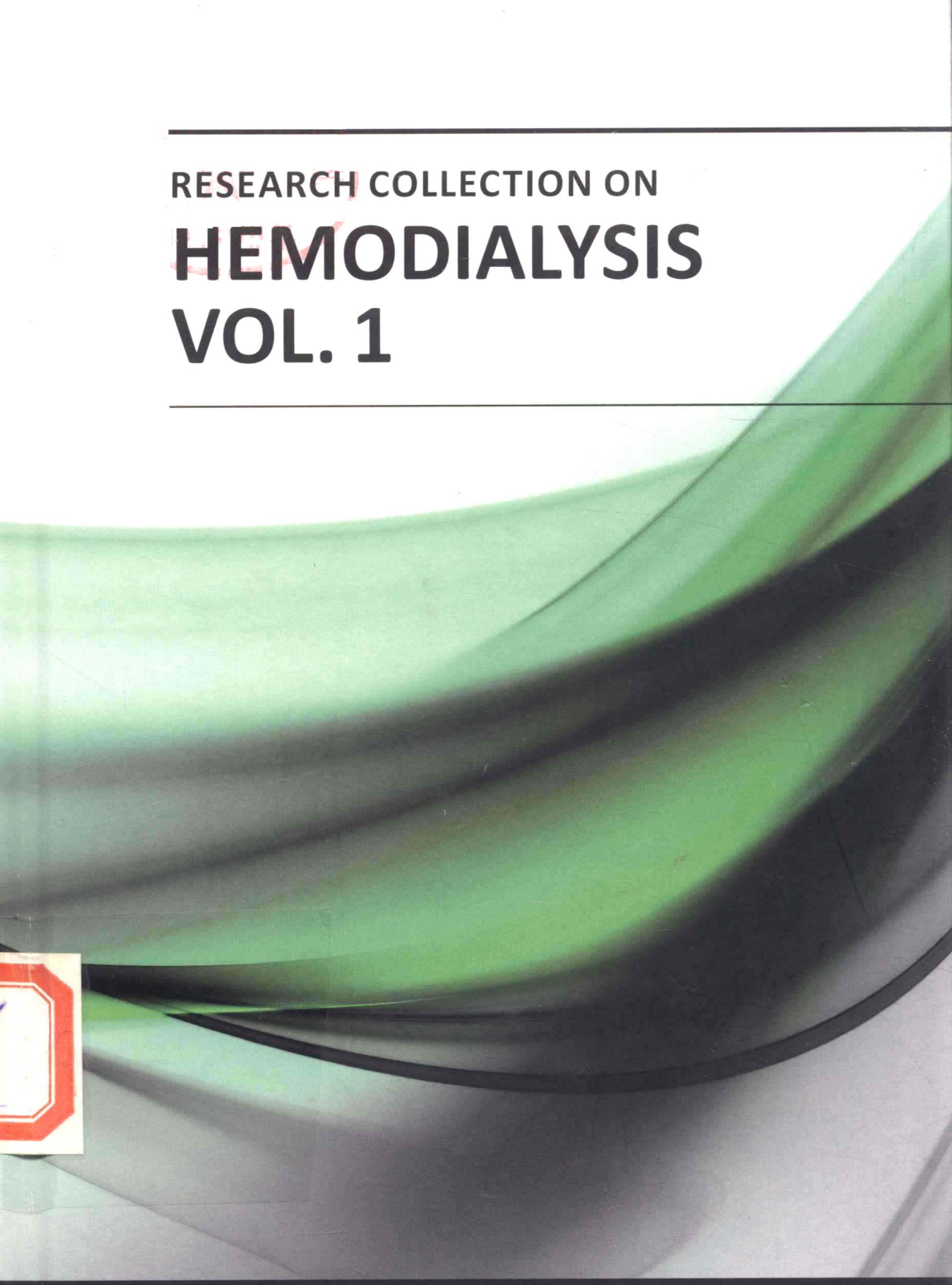
RESEARCH COLLECTION ON

HEMODIALYSIS VOL. 1



INTECH

RESEARCH COLLECTION ON HEMODIALYSIS VOL. 1

Research Collection on Hemodialysis Vol. 1

http://dx.doi.org/10.5772/ 58121
Chapters from books edited by: **Hiromichi Suzuki** and **Maria Goretti Penido**

Published by InTech

Janeza Trdine 9, 51000 Rijeka, Croatia

Edition 2014

Notice

Statements and opinions expressed in the chapters are these of the individual contributors and not necessarily those of the editors or publisher. No responsibility is accepted for the accuracy of information contained in the published chapters. The publisher assumes no responsibility for any damage or injury to persons or property arising out of the use of any materials, instructions, methods or ideas contained in the book.

Additional hard copies can be obtained from orders@intechopen.com

Research Collection on Hemodialysis Vol. 1

p. cm.

ISBN 978-953-51-1537-3

Contents

RESEARCH COLLECTION ON HEMODIALYSIS VOL. 1

Research Collection on Hemodialysis Vol. 1

http://dx.doi.org/10.5772/ 58121
Chapters from books edited by: **Hiromichi Suzuki** and **Maria Goretti Penido**

Published by InTech

Janeza Trdine 9, 51000 Rijeka, Croatia

Edition 2014

Notice

Statements and opinions expressed in the chapters are these of the individual contributors and not necessarily those of the editors or publisher. No responsibility is accepted for the accuracy of information contained in the published chapters. The publisher assumes no responsibility for any damage or injury to persons or property arising out of the use of any materials, instructions, methods or ideas contained in the book.

Additional hard copies can be obtained from orders@intechopen.com

Research Collection on Hemodialysis Vol. 1

p. cm.

ISBN 978-953-51-1537-3


INTECH
open science | open minds

Contents

Preface

This is the first of two volumes on hemodialysis.

Hemodialysis, which is used to remove waste products from the blood when the kidneys are failing, carries the risk of a number of side effects, such as "dialysis washout", infections, metabolic complications and dialysis disequilibrium syndrome. This book describes these side effects in detail and also discusses the technical issues associated with vascular access, including placement and maintenance of arteriovenous fistula and the complications of fistula access, such as aneurysms, stenosis, thrombosis, steal syndrome and heart failure. Other key topics discussed in the book are management of fluid status/hydration; antidiabetic therapy for type 2 diabetes patients who are on hemodialysis; nutritional assessment and therapy; and the different types of prosthetic grafts for hemodialysis and their complications.

The book will also describe some emerging technologies and concepts in hemodialysis, including new membrane materials, the use of mathematical/computer-based modeling for evaluating hemodialysis efficiency, and work being done to develop hemodialysis techniques that can remove large and protein-bound molecules.

We believe that this book will be an authoritative reference work, both for clinicians specializing in renal medicine and for biomedical researchers, and we also hope that it will provide ideas and stimulus for further research.

PROGRESS IN HEMODIALYSIS – FROM EMERGENT BIOTECHNOLOGY TO CLINICAL PRACTICE

Edited by **Angelo Carpi, Carlo Donadio** and **Gianfranco Tramonti**

Kinetic Modeling and Adequacy of Dialysis

Malgorzata Debowska[1], Bengt Lindholm[2] and Jacek Waniewski[1]
[1]*Institute of Biocybernetics and Biomedical Engineering, Polish Academy of Sciences, Warsaw,*
[2]*Divisions of Baxter Novum and Renal Medicine, Karolinska Institutet, Stockholm,*
[1]*Poland*
[2]*Sweden*

1. Introduction

The mathematical description of hemodialysis (HD) includes two parts: 1) explanation of the exchange between patient's blood and dialysate fluid across a semipermeable membrane of the dialyzer, and 2) characterization of the solute removal from the patient. The solute transport across the dialyzer membrane depends on the difference in hydrostatic pressure and solute concentration gradients between both sides of the membrane and also on the permeability of the membrane to the solute. The local equations for solute and fluid transport through the membrane are based on a phenomenological (thermodynamic) description according to the Staverman-Kedem-Katchalsky-Spiegler approach (Staverman, 1951; Kedem & Katchalsky, 1958; Katchalsky & Curran, 1965; Spiegler & Kedem, 1966). The two compartment model describes the functioning of the patient - dialyzer system, assuming that body fluid is divided into two parts: one directly (extracellular compartment) and one indirectly (intracellular compartment) accessible for dialysis (Schneditz & Daugirdas, 2001). The one compartment model of the solute distribution volume assumes that the solute is distributed in a single, homogenous pool. Solute kinetic modeling is based on a set of ordinary differential equations describing the changes of solute mass, concentration and distribution volume in body compartments and in the dialyzer. Using solute kinetic modeling one is able to evaluate dialysis efficiency.

The question concerning dialysis dosing has been debated and remains controversial since the beginning of the dialysis treatment era. Between 1976 and 1981, the National Cooperative Dialysis Study (NCDS) was performed in the United States to establish objective, quantitative criteria for the adequate dose of dialysis (Gotch & Sargent, 1985; Sargent & Gotch, 1989; Locatelli et al., 2005). The primary analysis showed that morbidity was less at lower levels of time average urea concentration. The secondary 'mechanistic' analysis of the NCDS data done by Gotch and Sargent launched the issue of urea KT/V (Gotch & Sargent, 1985).

Single-pool KT/V overestimates the removed amount of urea because of the postdialysis urea rebound, i.e., a fast postdialysis increase in urea concentration in plasma, which is a compartmental effect; therefore, the equilibrated KT/V (eqKT/V), estimated by the Daugirdas formula, was introduced to clinical practice (Daugirdas et al., 2001). Equilibrated KT/V values can be also calculated using an alternative equation by Daugirdas and

Schneditz (Daugirdas & Schneditz, 1995), or the formula derived from observations during the HEMO Study (Depner et al., 1999; Eknoyan et al., 2002; Daugirdas et al., 2004), or that introduced by Tattersall et al. (Tattersall et al., 1996).

The usage of the KT/V index as a sole and optimal measure of dialysis dose is questioned by many authors. Fractional solute removal (FSR) and equivalent continuous clearance (ECC) are two such alternative options, which can be used instead of KT/V. FSR was suggested by Verrina et al. (Verrina et al., 1998) and Henderson (Henderson, 1999) for comparative studies of various dialysis modalities and schedules. By definition FSR is the removed mass over the reference solute mass in the body. The concept of FSR is closely related to the concept of the solute removal index (SRI) proposed by Keshaviah (Keshaviah, 1995). Standard KT/V (stdKT/V), introduced by Gotch, is another variant of FSR (Gotch, 1998). The time-average solute concentration (C_{ta}) has been introduced to define 'equivalent renal clearance' (EKR), as a solute removal rate over C_{ta} (Casino & Lopez, 1996). Using other reference concentrations in the definition of EKR instead of C_{ta}, the general idea of equivalent continuous clearance, ECC, can be formulated (Waniewski et al., 2006; Waniewski et al., 2010). There are at least four different reference methods: 1) peak, p, 2) peak average, pa, 3) time average, ta, and 4) treatment time average, trta, reference values of volume, mass, and concentration applied in KT/V, FSR and ECC (Waniewski et al., 2006; Waniewski et al., 2010). KT/V, FSR and ECC are mathematically related for the same reference method. However, the choice of an adequacy index and the respective reference method is not obvious. It is not possible to decide whether this or the other definition is better although some authors have declared their preferences (Keshaviah, 1995; Casino & Lopez, 1996; Verrina et al., 1998; Henderson, 1999). The difference between different hypotheses and the indices based on them may be investigated theoretically, but the choice, if any, may be done only on the basis of a large set of clinical data. Future research should hopefully provide more information about the relationship between various definitions and the probability of clinical outcome in dialyzed patients.

Recent studies report some advantages of low-efficiency, frequent schedule over short, high-efficiency HD (Depner, 1998; Charra et al., 2004). The two compartment variable volume urea kinetic model can be applied to examine the whole set of dialysis adequacy indices in different dialysis treatments, e.g. 1) conventional HD with 3 sessions per week, 2) daily HD with 6 sessions per week and 3) nocturnal HD with 6 long sessions using typical patient and treatment parameters. The peak average reference method used in FSR and ECC calculations seem to be a more sensitive to the frequency and time of dialysis than the method based on time average reference (Waniewski et al., 2006; Waniewski et al., 2010).

The unified approach to the definition of dialysis adequacy indices proposed by Waniewski et al. is valid for all modalities of dialysis performed in end-stage renal disease and acute renal failure patients and for the assessment of residual renal function (Waniewski et al., 2006; Debowska et al., 2010; Waniewski et al., 2010). The integrated system of dialysis adequacy indices takes into account all currently applied indices and allows to explain their relationships and specificities.

The theory and practical application of this system of adequacy indices are here presented on the basis of our previous publications and a (unpublished) PhD thesis (Waniewski & Lindholm, 2004; Debowska & Waniewski, 2005; Debowska et al., 2005; Waniewski et al., 2006; Debowska et al., 2007a; Debowska et al., 2007b; Debowska et al., 2010; Waniewski et al., 2010).

2. Theory of fluid and solute transport in hemodialysis

The mathematical description of hemodialysis includes two parts: 1) one part that explains the fluid and solute transport across a semi-permeable membrane of the dialyzer, and 2) one part that characterizes the global solute transport between removal device and patient.

2.1 Solute and fluid transport in dialyzer

The fluid and solute transport in dialyzer consists of two processes: transport through a permselective membrane between blood and dialysate and transport in blood and dialysate channels.

The theoretical description of transport through a permselective membrane is based on phenomenological (thermodynamic) descriptions according to the Staverman-Kedem-Katchalsky-Spiegler approach (Staverman, 1951; Kedem & Katchalsky, 1958; Katchalsky & Curran, 1965; Spiegler & Kedem, 1966; Weryński & Nowosielcew, 1983; Werynski & Waniewski, 1995; Waniewski, 2006). Diffusion is the dominant factor for small solute transport in hemodialyzer. The transport due to convection prevails in hemofilters, plasma separators, etc. In hemodialyzer with highly permeable membrane used in hemodiafiltration, the convective transport component plays a leading role in the removal of middle molecules and small proteins (Werynski & Waniewski, 1995).

Considering the dialyzer as shown in Fig. 1, the system will soon after the start of dialysis be at the quasi-steady state with the mass balance:

$$Q_{b,i}C_{b,i} + Q_{d,i}C_{d,i} = (Q_{b,i} - Q_v)C_{b,o} + (Q_{d,i} + Q_v)C_{d,o} \tag{1}$$

where $Q_{b,o} = Q_{b,i} - Q_v$ and $Q_{d,o} = Q_{d,i} + Q_v$ are the rates of blood and dialysate flows at the outlet of hemodialyzer, respectively, Q_v is ultrafiltration rate, $C_{b,i}$ and $C_{d,i}$ are the inlet blood and dialysate concentrations and $C_{b,o}$ and $C_{d,o}$ are the outlet blood and dialysate concentrations, respectively.

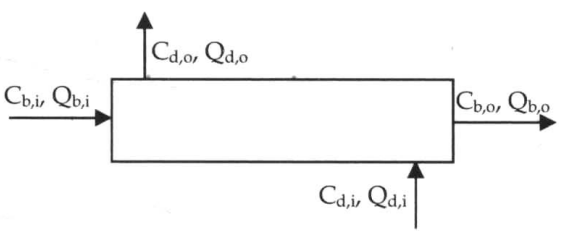


Fig. 1. Schematic description of concentration and flows in dialyzer.

After rearrangement of equation (1):

$$Q_{b,i}(C_{b,i} - C_{b,o}) + Q_v C_{b,o} = Q_{d,i}(C_{d,o} - C_{d,i}) + Q_v C_{d,o} \tag{2}$$

The left side of equation (2) represents the solute leaving the blood; the right side is the solute appearing in dialysate. The first term on each side of equation (2) is the diffusive component of flux and the second term represents the convective contribution.

At any specific blood and dialysis fluid flow rates, the diffusive dialysance D is the change in solute amount of incoming blood over concentration driving force ($C_{b,i} - C_{d,i}$):