Exploring Engineering Solutions in the Hope of Improving Dialysis Care

AO Ojo

ABSTRACT

Background: *This study investigated aspects of dialysis care which are often neglected. It looked at patient comfort and aspects of treatment that patients would like to see improved which were amenable to an engineering solution.*
Methods: *The results were obtained from 12 patients at the Scarborough General Hospital's Dialysis Center, located at 78 Corporate Drive, Scarborough, Ontario.*
Results: *The significant areas of concern identified were discomfort, waiting times and blood clotting, with 7/12 patients indicating distress associated with treatment, 7/12 patients expressing discontent with current waiting times and 8/11 patients reporting instances of blood clotting.*
Conclusion: *Novel methods to combat blood clotting and alleviate the discomfort associated with vascular access are proposed. In order to address concerns with waiting times and blood clotting, an integrated polymer based solution was developed. This approach is based on the multitude of properties achievable with the combination of polymers into a film and the surface modifier antithrombin-heparin (ATH) covalent complex. By utilizing a self-assembling and degradable film deposited as a coating on the portion of dialysis units which come into contact with a patient's blood, the disinfecting and cleaning operations can be greatly improved while reducing the possibility of thrombotic complications. The interface method proposed is a novel approach to vascular access intended to alleviate patient discomfort with needles.*

Keywords: Bioprosthetic, blood clotting, dialysis, heparin, polymer, thrombin

Explorando Soluciones de Ingeniería Encaminadas a Mejorar la Atención de Diálisis

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RESUMEN

Antecedentes: *Este estudio investigó aspectos de la atención de diálisis que a menudo se descuidan. En el mismo se abordan la comodidad del paciente así como aspectos del tratamiento que los pacientes les gustaría ver mejorados y que son susceptibles de una solución de ingeniería.*
Métodos: *Los resultados se obtuvieron de 12 pacientes del Centro de Diálisis del Hospital General de Scarborough, situado en 78 Corporate Drive, Scarborough, Ontario.*
Resultados: *Las áreas importantes de interés identificadas fueron las molestias, los tiempos de espera y la coagulación: 7/12 pacientes indicaron malestar asociado con el tratamiento, 7/12 pacientes expresaron su descontento con los actuales tiempos de espera, y 8/11 pacientes reportaron casos de coagulación de la sangre.*
Conclusión: *Se proponen nuevos métodos para combatir la coagulación de la sangre y aliviar la molestia asociada con el acceso vascular. Para resolver problemas con el tiempo de espera*

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y la coagulación de la sangre, se desarrolló una solución de polímero integrado. Este método se basa en la multitud de propiedades que pueden alcanzarse combinando los polímeros para formar una película, y complejo covalente antitrombina-heparina (ATH) como modificador de superficie. Mediante la utilización de una película degradable y capaz de autoensamblado, depositada como un revestimiento sobre la parte de las unidades de diálisis que entran en contacto con la sangre del paciente, las operaciones de limpieza y desinfección pueden ser mejoradas reduciendo la posibilidad de complicaciones trombóticas. El método de interfaz propuesto constituye un abordaje novedoso al acceso vascular para aliviar el malestar del paciente con las agujas.

Palabras claves: Bioprotésico, coagulación, diálisis, heparina, polímero, trombina

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INTRODUCTION

Kidney disease is a life-threatening condition characterized by high mortality rates, exorbitant costs and diminished quality of life. Kidney failure results in the accumulation of harmful wastes, and the retention of fluid which lead to hypertension and other physiological disturbances.

Haemodialysis is used to treat patients with kidney failure, but unfortunately does not fully replace kidney function. Patients often develop complications such as cardiovascular disease. Patients may suffer from abnormal blood pressure necessitating intervention (1). There are many approaches to treating kidney failure. Short daily haemodialysis and daily home nocturnal haemodialysis are promising alternatives that can improve the quality of life experienced by patients, control blood pressure and improve anaemia. Nocturnal haemodialysis has been shown to additionally control phosphate levels eliminating the need to use phosphate binders, allow for a less restrictive diet and also correct sleep apnoea (2). The focus of this study is to address the mechanics of treatment. The objective was to develop engineering solutions to improve the quality of care patients receive, address areas of concerns, alleviate discomfort and optimize dialysis based on discussions with patients.

SUBJECTS AND METHODS

Participants

The study was conducted at the Scarborough General Hospital's Satellite Dialysis Center, located at 78 Corporate Drive, in Scarborough, Ontario. A total of 12 patients provided feedback for the study.

Dialysis treatments

One patient had just begun receiving dialysis treatment three weeks prior to the study. The remainder of the patients had been receiving haemodialysis for at least one-year. The patients were treated with conventional haemodialysis three times a week.

Data analysis

One proportion tests were conducted on the data collected with Minitab's Statistical Software. A 90% confidence interval is given for the reported proportions.

RESULTS

Most patients experienced some form of discomfort with their dialysis treatment. While each patient's experience was unique, there were common areas of concern that could be addressed. Patient discomfort and clotting were experienced by a majority of the patients. A novel method to combat blood clotting and alleviate discomfort with vascular access is proposed.

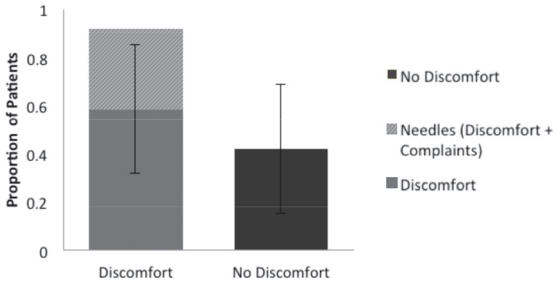

Fig. 1: Discomfort associated with haemodialysis treatment.

Discomfort was determined to be a common aspect of haemodialysis with 7/12 patients indicating distress associated with treatment. The origins and causes of the discomfort varied greatly between patients. Some patients reported episodes of tremendous pain both during and after treatment while others did not report any case discomfort. In an extreme case, the pain was characterized as debilitating with soreness throughout the entire

body that led to the hospitalization of the patient on several occasions.

Others complained of muscle cramping during treatment. Changes in muscle perfusion in order to compensate for a reduction in blood circulating throughout the body and changes in blood composition could play a role in cramping (3). The composition of the dialysate is intended to removed waste from the blood while maintaining the proper ion concentration in the blood. If the balance is not maintained, cramping could arise due to alterations in neuromuscular transmission (3). Inadequate blood perfusion may lead to cramps if the tissue's oxygen demands are not being met. Drugs such as quinine, carnitine, prazosin and Vitamins E and C have been shown to decrease cramping through a variety of mechanism and can be administered to patients experiencing cramping (3).

Patients also expressed discomfort regarding their stay at the treatment centre and provided recommendations to improve their patient experience. Serving refreshments and sandwiches for patients waiting for their sessions was suggested as an inexpensive way to improving patient utility, however, this is not done because blood flow to the splanchnic beds may cause hypotension while undergoing dialysis. Many slept or watched TV during treatment and reported that they would enjoy moving around and the possibility of exercise. Given the size and set-up for the Haemodialysis Units, mobility is likely unattainable. However, simple leg exercise units and refreshments are attainable given their cost in relation to the annual cost per patient of around $60 000 US dollars in 2003 (4). A study by Parsons *et al* highlighted the benefits of exercise during treatment. Improvements were seen in clearing toxins and increasing overall physical stamina (5).

Associated conditions

It was hypothesized that there would be a correlation between the number of years with kidney failure and age with the number of associated conditions the patients suffer from. However, no observable trends can be noted from the study. Instances of associated conditions did not vary with either age or length of dialysis treatment. It cannot be concluded that the number of conditions a patient suffers from is related to their age or length of dialysis treatment. Diabetes mellitus, however, was the most prevalent condition afflicting dialysis patients with four of seven patients who reported a health complication suffering from diabetes. This is much higher that the instance of diabetes in the general adult population of Ontario, Canada, which is 11/125 persons (6). This confirms the long-established and well-known relationship between diabetes and kidney disease. Diabetic nephropathy is the leading cause of kidney failure in the United States of America (USA) which would be very similar to the situation in Canada (7). Studies of the Ontario population in 2005 indicate that approximately 800 000 men and women suffer from diabetes (6). These individuals are at greater risk of kidney failure during their lifetime.

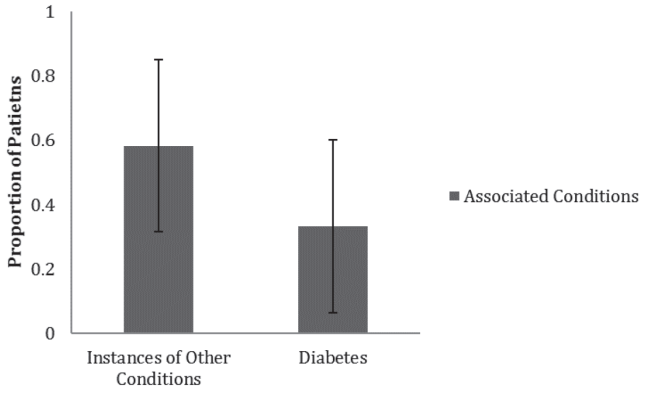

Fig. 2: Medical complications present in the haemodialysis patient population. Instances of diabetes other condition such as hypertension are expressed as proportions relative to the total patient population.

Time and blood clotting

Treatment time and blood clotting were identified as major concerns of dialysis treatment, with 7/12 patients expressing discontent with current waiting times and 8/11 patients reporting instances of blood clotting. Results regarding an ideal length of dialysis session were not conclusive. Responses were predominantly influenced by patient mobility and employment. Increasing the number of dialysis sessions and reducing the time of each one was received with mixed results. For instance, one patient was content with the three sessions of dialysis he received per week for three and a half hours as his ses-

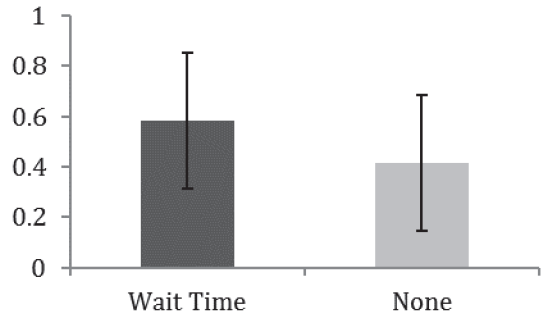

Fig. 3: Patient's concern with treatment time. Results indicate that a significant proportion of patients are unsatisfied with treatment times, particularly wait times.

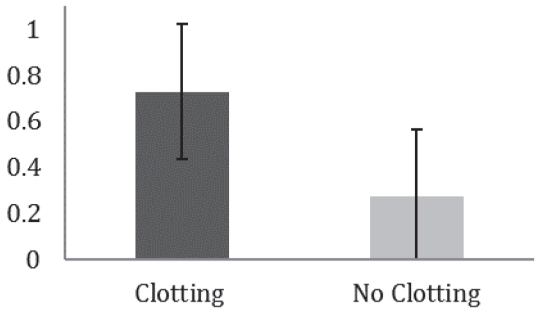

Fig. 4: Proportion of patients who experienced blood clot complications during haemodialysis treatment.

sions conveniently fell between shifts at work. Mobility was a concern for elderly patients who relied on wheeltrans and public services for transportation.

DISCUSSION

Despite the risks associated with haemodialysis, it has the capacity to extend the lives of patients by preventing the build up of harmful waste in the body. This study gives insight into an aspect of dialysis treatment often neglected, patient comfort and the aspects of treatment that patients would like to see improved. The responses from patients identified common areas of concerns. Novel methods to combat blood clotting, alleviate discomfort with vascular access, improve sterilization, and reduce waiting times are proposed

Dialysis machine coating

In order to address concerns with waiting times and blood clotting an integrated polymer based solution is proposed. The foundation of this novel approach is the multitude of properties achievable with the combination of polymers into films. The goal is to reduce the time needed for the sterilization of Dialysis units between patients while increasing effectiveness and reducing the possibility of thrombotic complications.

The disinfecting process for dialysis units is extensive and requires a great deal of resources and time. Currently bleach is used as the primary disinfectant followed by rinsing with high purity water. Dialox is an example of another commercial cleaner which can be used. Its powerful germicide is effective for dialyzer reuse (8). The standard method for cleaning dialysis units involves cycling the disinfectant solution through the unit with the hope that all contaminants would be been removed and pathogens killed (8). In order to remove residue from the cleaning products, dialysis machines are then rinsed with high purity. Dialysis units are effectively cleaned in this manner; however, the process has a number of drawbacks. Time and resources are the most significant disadvantages. A technician must be present, to operate the process, increasing the operating cost of the Dialysis Centers and the cleaning solutions and high purity water required for rinsing are costly. Additionally, the duration of cleaning limits the number of patients who can receive treatment.

By utilizing a heterostructure multilayer film, as described by researchers from the Department of Materials Science and Engineering at MIT, fabricated by the spontaneous self-assembly polymer coating onto a substrate, the disinfecting and cleaning operations can be greatly improved (9).

The basement substrate allows for the deposition of a polymer layer which could destabilize in the presence of light or degrade when subjected to a change in pH. The polymer used for the top surface creates smooth anticoagulant surface utilizing an antithrombin-heparin (ATH) covalent complex. This surface modifier is currently being used to achieve biomaterials with thromboresistant properties (10). Between patients, the degradable layer is activated allowing the patient's blood and any possible contaminants to be swept away with the top layers of the dialysis unit's coating.

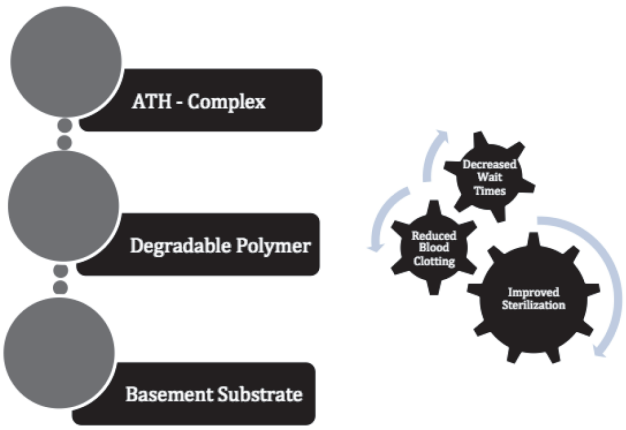

Fig. 5: Novel dialysis unit coating with a basement substrate that allows for the deposition of a degradable polymer layer. The degradable polymer allows the coating of the machine to be renewed. Between patients the degradable layer is activated allowing the patient's blood and any possible contaminants to be swept away with the top layers of the dialysis unit's coating. The polymer used for the top surface creates a smooth anticoagulant surface utilizing an antithrombin-heparin (ATH) covalent complex.

The deposition process can be repeated in order to produce a film with the desired properties and thickness, allowing for control at the molecular level (9). The

process involves applying a dilute aqueous solution of a polycation to a substrate, rinsing the substrate with water followed by the application of a complementary polyanion solution. Substrates were submerged in charged polymer solutions for as little as two minutes and subsequently washed and rinsed with dilute hydrochloric acid. After the deposition of each subsequent layer, the film was air-dried.

This proposed coating for dialysis machines would improve blood flow, reduce instances of clotting, and decrease cleaning time.

Vascular access

Improvements to alleviate the discomfort associated with needle use in haemodialysis can be garnered from conditions that require repetitive injections and needle use. The approach proposed consists of a permanent interface for vascular access. If an interfacing membrane could be developed which would allow for the vascular access at a permanent location much of the stigma and pain associated with needle use could be alleviated. Needles were the greatest factor contributing to discomfort with 4/7 patients reporting needles as a cause of their discomfort.

There seemed to be a preference among most patients toward a direct line approach. However, line use is limited by treatment effectiveness and is ultimately at the discretion of the patent's nephrologists. The novel approach to vascular access being proposed is a combination of a heart valve to control blood flow and interfacing mechanism to achieving a simple sterile solution as shown in Fig. 6.

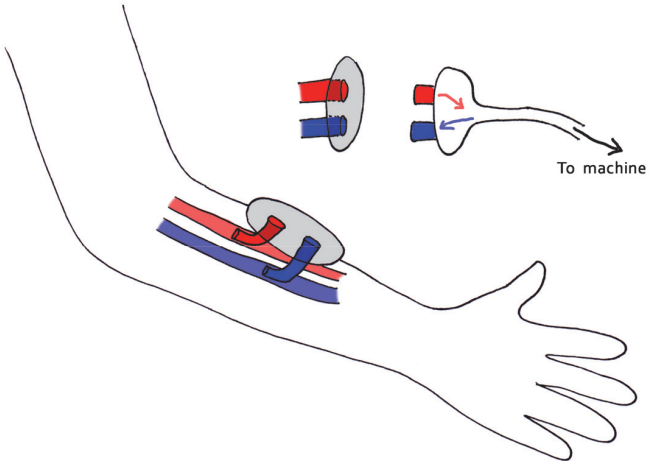

Fig. 6: Universal membrane interface allowing blood to be removed, filtered, and returned to the patient without the discomfort of needles. A permanent and common interface would reduce wait times by streamlining blood removal, discomfort by eliminating needles, clotting complications and instances of infection by utilizing degradable anticoagulant coating. Following treatment sterilization and isolating the connection from the patient's surrounding with preservatives would further reduce the possibility of contamination and infection.

Prosthetic valves

Two types of materials are used for artificial valves – biological tissue and abiotic surfaces such as metals and plastics modified to improve biocompatibility. Several factors are considered in the evaluation of each and are discussed below.

Life span and cost

Bioprosthetic valves, which are made from biological tissue, could be used despite their limited life spans in cardiovascular applications as the loads during haemodialysis will be less strenuous and also occur less often. Rather than expensive and limited heart valve tissue, vascular tissue which is a readily available substitute would be used. Between haemodialysis sessions, the glutaraldehyde originally used to strengthen and preserve the valves could be returned to the void between the complimenting bi-leaf valves. Due to their biological nature and lack of exposed foreign antigens resulting from the application of glutaraldehyde, the risk of blood clot formation will be low and further reduced by the anticoagulants received by dialysis patients and the novel machine coating proposed below which includes a surface modifier complex. Bleeding complications occur less frequently in patients with tissue valves than patients with mechanical valves and this again favouring a tissue based approach (11).

Sterilization

Prior to and following treatment, the units should be sterilized to further reduce the possibility of contamination and infection. Once filled with preservative, the connections will be fully isolated from the patient's surrounding. The interfacing method described above may not be the ideal in terms of cost effectiveness at the moment but could prove worthwhile reducing patients waiting times, discomfort, clotting complications and instances of infection and become a more feasible technological improvement that reduce the cost of tissue engineering.

CONCLUSION

Great strides have been made in the treatment of kidney failure. As dialysis care continues to evolve and improve with the development of new technologies, there are great hopes that kidney disease treatments will become safer, less invasive and more comfortable. Engineering solutions can play a large role in these developments. A novel polymer based solution implemented with the unit's coating and a universal membrane interface could be steps in the right direction towards improving patient care and decreasing waiting times associated with current methods of unit sterilization methods.

The small sample size was a limitation of the study, future research in this area should be directed at increasing the scope of the study and developing deposition models for the dialysis unit coating.

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