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Research Article

Experiences with Large-Bore Catheters as Vascular Access for Extracorporeal Detoxification Methods - a

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ABSTRACT

After the introduction of large-bore catheters with the Seldinger technique into the vena cava superior via internal jugular veins in 1979, the advantages of this puncturing technique versus the puncture of the femoral and subclavian veins were observed. But complications and side effects of this puncturing technique were found, too. Besides the complications such as faulty puncture, bleeding, hematothorax, thrombosis and faults in catheter material the infections and septicaemia are the most severe.

Background: catheter-related infections, thrombosis and stenosis are among the most frequent complications associated with catheters which are inserted in vessels as vascular access. These complications are usually related to the handling of the staff, the catheter materials, and the surface properties of the catheter. To reduce such complications especially Catheter-Related Infections (CRI), catheters with surface treatments of the outer surface, such as ion beam assisted deposition were investigated in a retrospective study, to prove if the surface treatment of the catheters is sufficient to reduce the high infection rate.

Methods: The study from 1992 – 2007 evaluated silver coated and non-coated as a control implanted large-bore catheters for hemodialysis or apheresis methods. The catheters were inserted under sterile conditions into the internal jugular or subclavian veins. After removal, the catheters were cultured for bacterial colonization using standard microbiologic assays. Pieces of these catheters were also examined using a Scanning Electron Microscope (SEM).

Results: The coated catheters with argent only on the outer surface showed a tendency towards longer in situ time. The microbiologic examinations of the catheter tips were in both catheter types high positive, but not significant.

Conclusion: The coated catheters with argent, only on the outer surface, showed no significant reduction in infection rate by evaluation of all collected data in this retrospective study. There was no association between the surface treated and the untreated catheters in significantly reducing patient discomfort. Other technologies which include the outer and inner surface are necessary. To reduce the tremendous high costs of the catheter-related infections new materials and new technologies must be developed, which should have a better biocompatibility. These requirements show perhaps the new material such as the microdomain structured inner and outer surface, as an example, are considered more biocompatible because they mimic the structure of natural biological surface.

Keywords: Large-Bore Catheters for Extracorporeal Detoxification Methods; Catheter-Related Infections; Surface Treated Catheters; Ion Beam-Assisted Deposition (IBAD) Technologies; Microdomain-Structured Surface (PUR-SMA Coated Catheter)

INTRODUCTION

Despite all technical innovations in hemodialysis the problem of finding a temporary or permanent vascular entry point appears to have found no satisfactory solution. Temporary vascular access, in particular, still presented considerable problems over years. For almost 2 decades, the method of choice a temporary vascular access for hemodialysis has been the transcutaneous puncturing using the Seldinger technique to insert a large-bore catheter, traditionally in the femoral or subclavian veins.

In 1979 we became aware of the problems associated with vascular access points for acute hemodialysis and we began to investigate another access point and introduced the cannulisation of the superior vena cava over the internal jugular vein with a modified large-bore catheter [1]. With the introduction of catheterization, the previously necessary application of a Schribner shunt has become superfluous. Catheterization of the internal jugular and subclavian vein as temporary access points is suitable for almost all treatment situations [2].

Contraindications for the internal jugular vein catheterization are low such as inflammations at the point of puncture and unidentified anatomical conditions, e.g., extended stream or tumors in the neck area. After insertion of the catheter in the internal jugular or subclavian vein, the position of the catheter tip should be checked fixing the catheter with a suitable cutaneous suture. In order to avoid x-ray control, we have been locating the catheter tip with an intra-atrial electrocardiogram passed over the catheter [3].

With the single lumen catheter only the single-needle method is practicable and suitable for hemodialysis or apheresis methods. With the single-needle method a blood flow of up to 400 ml/min. can be achieved with the double head pump or other single needle techniques. With double lumen large-bore catheters the normal two needle method is carried out [2].

Between each individual treatment the catheter lumen usually is kept free with a low-dose heparin drip (100-300 heparin/hr.). For outpatients, the catheter is filled with a heparinised NaCl solution, and/or an antibiotic solution, and stoppered. More recently the catheter was closed with a special developed mandarin who completely fills the catheter.

The catheterization of the femoral vessels as described by Shaldon et al. [4], and Kjellstrand et al. [5] produces more complications than the catheterization of the Superior Vena Cava (SVC). Cannulation of the SVC versus the subclavian vein as described by Schwarzbeck et al. [6], De Cubber et al. [7], and Uldall et al. [8] is difficult to implement and involves a higher complication rate. Using the infraclavicular catheterization technique, it is often difficult to push the large-bore catheter under the clavicle [9]. Perforation is more likely with a rigid catheter, apart from the danger of causing a pneumothorax or hematothorax due the anatomic position of the subclavian vein [7]. Therefore, we introduced in 1979 the catheterization of the SVC with large-bore catheters [1]. The cannulation of the SVC via the internal jugular vein appears to be a most appropriate route for rapid vascular access for hemodialysis and apheresis treatments and is used today as the first method worldwide.

Synthetic catheters, implants or other artificial systems are increasingly used for intensive medical treatments and of hemodialysis and apheresis procedures. Correspondingly, typical complications such as infections, especially catheter related infections, thrombosis, and materials faults of the catheters are also on the increase. CRI present a particular problem as they can appear at any time, even years after insertion or implantation, and may affect all materials. Complication rates due to infections for venous catheters are given at between 34 % and 40 % [9,10].

A further problem concerns the biocompatibility of the synthetic materials. The interaction of blood and synthetic surfaces causes

activation of the coagulation and complement system. These phenomena lead to the adsorption of various proteins and to the formation of a layer of protein on the synthetic surface. Thrombocytes and other blood cells follow and adhere to this layer of protein so that thrombi may form [11].

The adsorption phenomena were demonstrated by scanning electron micrographic studies of large-bore catheters after in situ in the venous blood stream for one to 4 weeks and longer in situ time. The continous magnification of a scanning electron microscope, over more than three orders of magnitude, and the large depth of field permit general and detailed images to be obtained directly from the specimen [10,11].

Due to the adsorption phenomena and the bacterial colonization of all investigated catheter materials, we looked for other catheter materials or techniques to minimize the bacteria settlements and the adsorption of blood substances on the surfaces, and we found new processes for surface treatment of catheters [12]. Catheters whose surfaces were treated with silver or silicone were investigated after removal in a Cam Scan scanning electron microscope. Bacterial colonization of the catheters was also investigated [13].

CATHETER AND MATERIALS

The first so-called Shaldon catheter has been frequently modified over recent years and all models available are of similar construction. With an inner diameter of between 1.5 and 1.8 mm the large-bore catheters are available in lengths of 80 to 200 mm, the tip terminates in a cone. On the side of the catheter, depending on the model, 6-12 perforations are found to guarantee more effective blood flow and to prevent the catheter from adhering to the vascular wall. Some years ago, for various catheter models inner catheter were available which can be inserted under sterile conditions after each hemodialysis treatment and left in place until the next dialysis treatment. These inner catheters closed the catheter bore and thus prevented the intraluminal formation of thrombi and provided additional security between treatments [14].

In recent years more and more modified single lumen and double lumen large-bore catheters were available, but some of these catheter types had considerable defects such as, for example, sharp edged tips, too rigid material, uneven transitions from catheter to the silicone tube connection and insufficiently adhering luer lock connectors, and faults in catheter materials [14].

For examples, Teflon catheters have a very smooth surface and thus a low thrombogenicity. Catheters are made of polyurethane which has also proved to be of good biocompatibility and low thrombogenicity and this material is somewhat more elastic than Teflon. Polypropylene is used as catheter material but its rough surface must be siliconized before use. Silicone catheters positioned by surgical implant techniques also have a good tissue compatibility [14].

Not all commercially catheters provide a contrasted picture when x-rayed. The incorporation of contrast medium presents no problem with polyurethane catheters while with Teflon material this may affect the durability of the material. Initially this leads to the catheter breaking at points where it is mechanically particularly stressed [15]. Other developments have resolved this problem but these catheters now have somewhat thicker walls. This can, however, lead to increased irritation of the endothelium. It is of decisive importance that the catheter material is well tolerated and of low thrombogenicity.

A further problem concerns the biocompatibility of the synthetic materials. Rarely do material properties perfectly match every requirement in a given application, and biomaterials are no exception [16]. It often becomes necessary to strike a compromise so that a material has acceptable properties in each pertinent area: the compromise is often between bulk and surface properties. For example, in a hemodialysis catheter – which demands both good flexibility and low surface friction – the best candidate may be slippery, less flexible material rather than a more supple one with unacceptable high friction. Dathe presented the aim of the best function with minimal interaction with the surrounding biological system [17]:

1) Chemical: biostabil, e.g., indifferent, do not get older or corrode.

2) Physical: observing the properties, elastic, good electrical characteristics.

3) Morphologic: smooth, slippery, water resistant, anti-adhesive.

4) Physiologic: no disturbance of the fluid flow, luminary flow.

5) Bacteriologic: bacteristatic, bactericide.

The contact of blood with synthetic surfaces causes activation of the coagulation and complement system. This leads to adsorption of various proteins and the formation of a layer of proteins on the synthetic surface [11,18]. On this layer of protein, thrombocytes and other blood cells adhere so that thrombi may form. One solution is the modification of surface properties, while preserving bulk attributes, thus improving the function and effective lifetime of catheter biomaterials to employ surface engineering by employing of biomaterial surface properties, including biological, mechanical, chemical, and other properties can be modified. Surface engineering is generally considered when a “good” surface is not good enough, when devices would not function without it, or when product differentiation is desired [16]. Most medical device companies have recognized the importance of surface-engineered biomaterials, because surface modification processes can reduce the rate of infection, thrombogenicity, and other catheter-related complications without affecting the basic design function of catheters. The range of services currently offered by surface treatment vendors is varied and continually expanding. Examples are conventional coating processes such as dipping and spraying; vacuum-deposition techniques (sputtering); and surface modification approaches such as diffusion (nitriding, carburizing); laser and plasma processes, chemical plating, grafting or bonding; and bombardment with energetic particles (plasma immersion or ion implantation). The techniques based on ionized particle bombardment have been particularly successful, because they combine versatility and low-temperature processing with superior process control, reliability and reproducibility [16].

Catheter with surface treatments of argent or silicone were investigated after their removal in a Can Scan scanning electron microscope and the bacterial colonization was also investigated [10,19-21]. The ion beam-based technologies used for the treatment of catheters are ion implantation and Ion Beam-Assisted Deposition (IBAD) [12,21], which are typically performed at low temperature under high vacuum (Spi-Argent, Spi-Silicone, Spire Corporation, Bedford, MA, USA). The affected layers in the ion implantation process, as well as the typical films deposited by the IBAD process, are on the order of 1 μm or less. Vacuum-compatible catheter materials may, therefore, be treated without adversely affecting

bulk mechanical properties [12,20,21]. Both ion implantation and IBAD are line-of-sight processes, which implied that only the outer surface of the catheters can be treated directly; however, parts with complicated geometries may be manipulated for uniform coverage of all surfaces. The ion implantation of silicone rubber catheters and the ion beam-assisted deposition of a silver coating are used [21].

STATISTICAL ANALYSIS

Statistical analysis was performed using the Statistical Package for Social Sciences (SPSS 13.0). All continuous data represented as mean ± standard deviation (SD) or if the data showed no normal distribution data were presented as a number (n) or in percent (%). Univariante, unadjusted analysis were performed with the independent samples t-test, chi-square test, Fisher´s exact test for frequencies at or below 5 and the Wilcoxon´s rank sum test. Pearson´s correlation coefficient was calculated and multivaria´s analysis was used to evaluate the presence of associated variables. Significance was defined at the 0.005 level.

RESULTS

After introduction of the cannulisations of the vena cava superior over the internal jugular vein, we observed complications as faulty puncture, bleeding, hematothorax, infections, thrombosis and faults in catheter material [2,10,22, 23]. In about 24 % of all inserted catheters we observed these complications. In the following years the complication rate could be reduced by better handling and more hygienic procedures and new catheter technologies such as surface treatment of the catheters [10,12,13].

Besides the catheter-related infections and other complications the biocompatibility of the synthetic catheter material was a further problem. The interaction of blood and synthetic surfaces causes activation of the coagulation and complement system which leads to the adsorption of various proteins and a layer of protein forms on the synthetic surface. Thrombocytes and other blood cells adhere to this layer of proteins so that thrombi may form. Pieces of these under sterile conditions removed catheters in a Can Scan scanning electron microscope were examined [10,11,24].

Layers of protein containing erythrocytes, thrombocytes and leukocytes both on the outer and inner surfaces appeared on catheters in situ for more than 3 days were observed, whereby the fibrin barely formed a lattice [24]. Large thrombi, completely filling the lumen and lateral openings, were also observed. Erythrocyte aggregates and agglutinated thrombocytes were present, too. Thrombocytes adhesion possibly precedes erythrocytes agglutination. In situ time of 8-10 days or more, catheters often completely covered by a coating consisting of 3 layers: the free surface of the thrombus consisted of dense, longitudinal fibrin fibres. Underneath there was a loose fibrin structure in which numerous blood cells were embedded. Another dense layer of protein was located directly on the catheter surface. Depending on the time the catheter remained in situ, these thrombi may have diameters of between 3-60 µm (Figure 1). Longer in situ times cause fibrin filaments to form on the edges of the thrombus. In the areas free of thrombi numerous monocytes were to be found in different phases of adhesion with so-called ruffle formation [24].

Bacterial colonization was observed in about 12 %. The incidence of catheter related infections between 8 and 20 % were to high, therefore surface treated processes with lower thrombogenicity and a lower contamination rate were introduced [12,25]. The surface treated processes uses ion implantation to improve the surface properties of silicone rubber with a high degree of reproducibility while bulk properties such as tensile strength, bulk modulus, and flexibility are remained (Spi-Silicone, Spire Corporation, Bedford, MA, USA). Ion beam-assistant deposition was used for catheter with silver-treated surfaces to create an infection-resistent actively sterile coating. This coating is bactericidal on contact, with minimal leading in the body, and biocompatible (Spi-Argent, Spire Corporation, Bedford, MA, USA). But only the outer the surface can be treated [26]. The method is an ion implantation technology. To improve the surface properties of the catheter material, energetic ions impinge on the catheter surface and penetrate in the near surface region. Ions interact with the catheter polymers and cause changes in the physical and chemical structures [21].

The catheters were removed under sterile conditions and pieces of the removed catheters were sputtered-coated with gold and examined in Can Scan scanning electron microscope at 15 to 20 kV. Catheters with treated outer surfaces showed a lower thrombogenicity and a lower contamination rate. Catheter with an in situ time lower than 3 days showed no deposits (Figure 2). The surface of a silver-treated catheter is uneven and ridged but without any deposits. An untreated inner surface shows fibrin fibers with thrombocytes and other blood particles. The outer surface of a silver-treated catheter was after 14 days of in situ time without a second layer. The untreated inner surface shows a second layer after 14 days, which consists of protein deposits, fibrin fibers and blood cells. The same results were observed with the silicone-treated surfaces.

In a study of 1998, 78 untreated and 78 surface treated acute and long-term catheters were investigated [26]. Of the untreated tips, 44.9 % cultured positive for bacteria. The blood culture in patients with untreated catheters, 51.3 % were positive and 64.1 % of the skin smears cultured positive for bacteria. Pathogenic Staphylococcus aureus was found in until 48 % of the untreated catheters. Other bacteria identified included Saprophytus and non-pathogenic Staphylococcus epidermidis in 8-53 % of the untreated catheters. In contrast to the 44.9 % bacterial colonization of the untreated tips, bacteria were found only 15.4. % of the surface treated catheter tips. In addition, in these patients only 17.9 % of the blood cultures and 37.2 % of the skin smears were positive. S. aureus and Pseudomonas were observed in 19 % of the positive skin, blood, and catheter tip cultures, and *S. epidemidis* was observed in 24 % [26].

Catheter-related infections were demonstrated besides the clinical symptoms by performing microbiologic examinations. Here some differences were overt in catheter investigations [26-30]. Of the untreated catheter tips, 55 % cultured positive for bacteria. Of the cultures in patients surface-treated catheters, 52 % were positive, not significantly lower. Although untreated catheters showed a lower infection rate with S. aureua, in treated catheters the infection rates with S. epidermidis, pseudomonas, and others such as saprophytes were not significantly lower (Table 1) [29].

Performing multivariate analysis, there was a strong association between catheters´ in situ period (R-square = 0.96), the number of treatment sessions (ß = 0.97, $p < 0.001$), and patients´ age (ß = 0.095, $p = 0.002$). There was no association between the in situ time and silver-coated/untreated catheters, results of the bacteriological examination, and patient diagnosis or outcome. Catheter malfunction or fibrin sheath formation as an outcome of both groups was not investigated [30].

Figure 1: Thrombus which completely covered the inner surface of a Teflon-catheter in-dwelling time 54 days [24].

Table 1: Microbiological examination of 105 untreated and 54 surface treated catheter (29).

Microorganism	Untreated (n)	(%)	Treated (n)	(%)	*p-value*
Negative	47	45	26	48	n.s
S.aureus	31	29	21	38	n.s
S. epidemidis	7	7	1	2	n.s
Pseudomonas	1	1	0	0	n.s
Enterobacter	1	1	1	2	n.s
Others	18	17	5	10	n.s

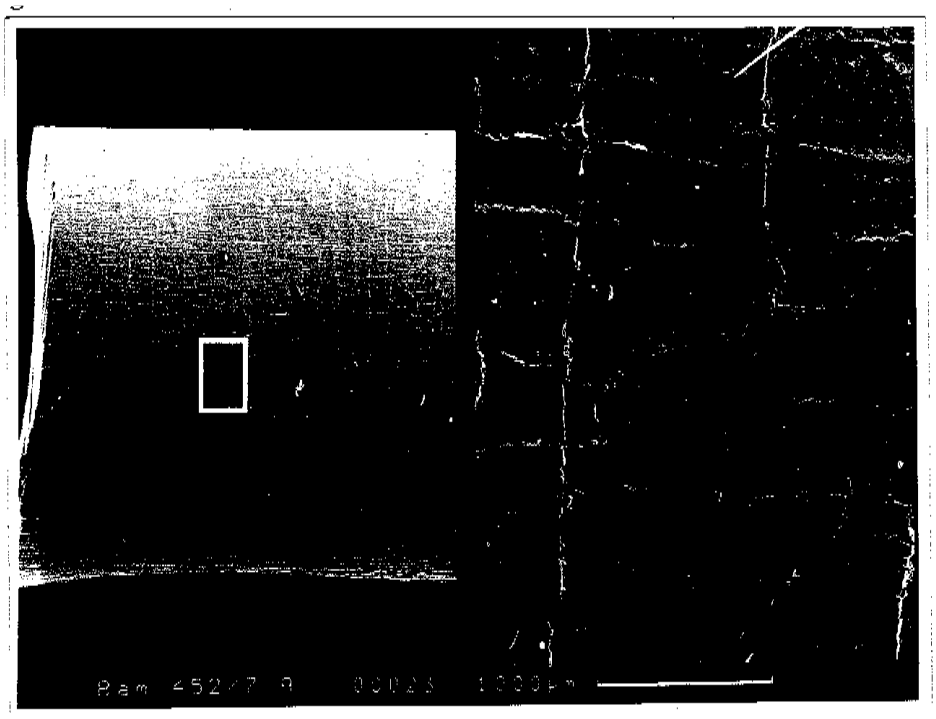

Figure 2: Outer surface of a Spi-Argent catheter (Spire Corporation, Bedford, MA, USA) without any blood deposits after in situ time of 38 days [25].

The decrease of the infection rate in surface-treated catheter in the preliminary study from 2001 cannot be seen in this presented study from 1992 – 2007. An explanation could be that all and more available data are no evaluated. The untreated catheters showed a higher positive culture for bacteria of 55 % versus 52 % to surface-treated catheters, but without significance. The procedure for both studies was the same [30].

DISCUSSION

After introduction of the cannulation of the superior vena cava via the internal jugular vein the advantages of this vascular access were observed as quick means of access, good patient´s mobility, CVP measurement possible, catheter advanced in straight, vessel lumen always open even in shock, suitable for risk patients, also for children etc. [23]. But more and more, infections and other complications were observed [10, 13, 25-29].

Catheter-related infections are the most dangerous complications of large-bore catheter associated with increased mortality aside from accidential puncture of an artery [31]. In addition to the catheter-related infections, biocompatibility of a catheter material is an important contributing factor to a successful outcome, particularly in catheters that remain in situ for several weeks or month. Although improved since the use of centrally placed catheters, the incidence of catheter clotting was previously high [28].

Catheter-related infections depend on the type of catheter, the organism identify, the complexity of the infection, and the handling of the catheters and not on the route of vascular access [32]. Infection rates from 5 % to 30 % and the most bacteria found is the S. aureus. Catheter-related S. aureus bacteremia are one of the main causes of morbidity and preventable cause of death in hemodialysis. Hemodialysis patients are at a high risk of S. aureus bacteremia and they have a four times higher mortality from central venous catheter-related *S. aureus* bacteremia than other patients [33-35].

Recent data have suggested that Methicillin-Resistant *S. aureus* (MDSRA) and Vancomycin Intermediate *S. aureus* (VISA) organisms may have increased in the last years [36]. One of the proposed reasons of vancomycin resistance is the bacterial cell wall thickening following vancomycin exposure [37]. Vancomycin´s activity may be decreased due to the thickness of the bacterial cell, the results are MSRA and VISA [38].

To reduce infection rates and thrombogenicity, coated catheters and cuffs with silver were inserted [39-41]. The clinical results of our preliminary investigations showed a significantly reduced infection rate in treated versus untreated catheters, a reduction of more than 75% [28]. With the silver surface treatment, a very smooth metallic surface was obtained which was responsible for a lower thrombogenicity rate. Silver ions are bactericidal, therefore, no bacteria growth is possible on the treated catheter surface. The positive association between the in situ time of the catheters and the patient's age may be because of an alteration of the immune system in elderly patients, especially in hemodialysis patients [30].

Table 2: Potential health care cost reductions that could be achieved through the use of surface-treated catheters (57)

Device	Hemodialysis	Average infection (%)
Annual usage (devices) in 1996	125,971	
Infection rate (%)	5-20	Rate 12
Cost ($) of complication (due to infection)	3.517	
Cost ($) of surface treatment	12	
Reduction of infections (%)	10-65	Reduction 40
Market size (1997) ($)	12.6 million	
Price ($) of each device (surface treatment)	120	
Savings ($) per year by using surface-treated devices	17.7 million	Reduction 40

In our retrospective study and all available data of all silver coated outer surface catheters no significantly reduction in infection rate, improvement, or life expectancy of silver coated versus uncoated catheters, which were inserted during 1992 and 2007, was observed. One reason can be that with the IBAD technology only the outer surface and not the inner surface is coated with silver or silicone. The postulated penetration of silver ions from the outer to the inner surface cannot be shown with these data. The outer treated surface catheters with silver or silicone have no advantage of reducing infection rate and improvement of patients versus the untreated catheters. The handling of the catheters under sterile conditions before, during and after extracorporeal treatments probably cannot prevent the contamination with bacteria, especially the untreated inner side.

Based on these results, new materials and techniques must be developed, which should have better biocompatibility to reduce side effects so that they can be left in situ for a longer time, because the part of dialysis patients with vascular problems is increasing in the last decade, and is now about 30 % of all hemodialysis patients. On reason is the age of HD patients which is permanent growing up [42]. Other possibilities to reduce the infection rate are the catheter impregnation with antimicrobial substances and the antibiotic lock solutions, i.e. heparin-vancomycin-ciprofloxacin, during the dialysis treatments [43,44].

As the requirement for more and more artificial organs and/or organ replacement increases, especially in elderly patients, there will be a definite need for new materials with better biocompatibility and for suitable technologies to get better improvement and to reduce the costs. A disadvantage of drugs such as antibiotics in the catheter surfaces or administration to patient or disinfection substances is that they can develop resistance by mutation or other mechanisms. Therefore new surgical techniques and materials are needed [45].

Other new materials must be developed, which should have better biocompatibility to reduce side effects so that can be left in situ for a long time, because the part of dialysis patients with vascular problems is increasing in recent years. The requirement for more artificial organs and/or organ replacement increase, therefore a definite need for new materials will be needed, with better biocompatibility and for suitable technologies to solve these infection, thrombosis and mechanical problems to get a better improvement of patients is very important and to reduce the costs. But it appears impossible to create a surface with an absolute "zero" adherence due to thermal-dynamical reasons and due to the fact that a modified material surface is in vivo rapidly covered by plasma and connective tissue proteins [30].

Other concepts of prevention of implant-associated infections must involve the impregnation of devices the inner and outer surfaces with antibiotics, antimicrobial and/or metals [43,44,46,47]. A further point is to understand the process leading to the development of catheter-related bacteremia in order to can offer effective preventive

and therapeutic possibilities [48] such as new polymer-antibiotic systems in inhibiting bacterial biofilm formation and in reducing neutrophil activation after surface contact on different biomaterials, thus reducing the risk for biomaterial-mediated inflammatory reactions [49-51], or the development of new biofilm to serve in a communication system termed quorum sensing [52], or molecules that inhibit quorum sensing signal generation among organism could block microbial biofilm formation [53, 54].

The catheter-related complications are contributing factors to the increasing cost of medical care. They are responsible for patient readmissions and longer hospital stays as well as patients discomfort, morbidity, and occasional mortality [30]. Feldmann et al. calculated in 1996 the cost of the morbidity due to catheter infections will soon exceed $ 1 billion per year [55]. For Japan Nakamura et al. calculated the costs for catheter in care units per patient at $ 57.090 [56]. Feldman et al. demanded to reduce vascular acess-related morbidity, that strategies must be developed not only to prevent and detect appropriately early synthetic vascular access dysfunction, but to better identify the patients in a whom radial arterio-venous fistula is a viable clinical option. The representative health care cost savings for hemodialysis catheters, given specific infection rates and potential infection rate reductions achieved by treated catheters [55].

The costs analysis was calculated using the literature and the available costs different companies which distribute these catheters [57]. Potential health care cost reductions that could be achieved through the use of surface treated catheters by annual usage of 125,971 hemodialysis catheter devices and an infection rate of 5%-20%, savings per year of $ 17.7 million, reduction about 40 % [58] (Table 2). Besides a high number of patients who die to End-Stage Renal Disease (ESRD), the costs of these infections are increasingly steady. Schwebel et al. calculated the costs of $ 2,118 / intensive care unit day, and Pronovost et al. of $ 45,000 per each infection [59,60]. Taconelli et al. estimated in 2009 costs associated with CRI in four European countries (France, Germany, Italy, and UK) between € 35.9 and € 163.9 million per year [61].

Due to these tremendous high costs it must be possible of scientists, physicians, bioengineers and others to develop new techniques and new materials to reduce these high costs and to increase the improvement of patients. But besides the high costs due to catheter-related infections, the patients´ longer hospital stays, and patients discomfort, mortality, and occasionally mortality are the most important problems which must be resolved. To reduce these complications it is necessary that the handling of the catheters must be done accurately first after the numerous recommendation and guidelines available in the literature and continued education is important in preventing catheter-related infections [62-64].

Surface treatment of catheter is necessary but both the inner and outer surface. New technology must be developed for surface treatment with antibiotics, antimicrobial substances and/or metal which are in part available today. New material and new-polymer-antibiotic systems are demanded. The developed of new biofilm to serve in a communication system termed quorum sensing [53] or molecules which inhibit quorum sensing signal generation among organism could block microbial biofilm formation [54]. This requirement shows perhaps the new developed catheter material, the microdomain-structured surface (PUR-SMA-coated catheters, Gambro, Germany) [30]. Microdomain surfaces are considered the most biocompatible because they mimic the structure of natural biological surfaces. Microdomain structures are used to match the multiple requirements for improved catheter surfaces that is reduced thrombogenicity and improved antimicrobial properties. The results with these catheters are very encouraged.

Most important is the improvement of the handling of the catheters by the attending staff which is recommended in numerous available guidelines to reduce the tremendous high costs to treat the ESRD and the discomfort and morbidity of the patients. Continued education in handling of the catheters is very important [65].

CONCLUSION

The results which we found in catheters which were surface treated only on the outside had no significantly advantages versus untreated catheters. In a retrospective study from 1992 to 2007, outer surface treated catheters with silver versus untreated catheters in 159 patients, who needed a large-bore catheter, were investigated. There was no association between the in situ time and silver coated/ uncoated catheters, resulting in the bacteriological examination, and patients` diagnosis or outcome. Reasons may be that on the surface treated catheters only the outer surface was coated with silver or silicone and the possibility of contamination by the handling during the extracorporeal treatments.

Therefore, new materials new surface treatments, and new technologies are needed to save the tremendous high costs for hemodialysis catheters by treating the complications, to reduce infection rates, and thrombus formations to improve the patients´ outcome and to reduce the tremendous costs.

REFERENCES

1. Bambauer R, GA Jutzler. Internal Jugular Puncture for Shaldon Catheterization. A new approach for acute hemodialysis. Kidney disease high pressure. 1980; 3: 109-116.
2. Bambauer R, GA Jutzler. Transcutaneous insertion of the Shaldon catheter through the internal jugular vein as access for acute hemodialysis. Dialysis & Transplantation. 1982; 9: 766-773.
3. Bambauer R, GA Jutzler. Positional control of large-lumen central venous catheter by intracardiac electrocardiography. Intensivmed. 1980; 17: 317-319.
4. Shaldon S, L Chiandussi, B Higgs. Hemodialysis by percutaneous catheterization of the femoral artery and vein with regional heparinisation. Lancet II. 1961: 857.
5. Kjellstrand CM, GE Merino, SM Mauer, R Casali, TJ Buselmeier. Complications of percutaneous femoral vein catheterization for hemodialysis. Clin.Nephrol. 1975; 4: 37. https://goo.gl/2UdwEi
6. Schwarzbeck A, WD Brittinger, GE v Henning, M Strauch. Cannulation of subclavian vein for hemodialysis using Seldinger´s technique. Trans Am Soc Artif Intern Organs. 1978; 27: 24. https://goo.gl/HmKeDf
7. De Cubber A, C De Wolf, N Lameire, M Schurges, S Ringoir. Single needle hemodialysis with the double head pump via the subclavian vein. Dialysis & Transplantation. 1978; 7: 1261.
8. Uldall PR, RF Dyck, F Woods. A subclavian cannula for temporary vascular access for hemodialysis or plasmapheresis. Dialysis & Transplantation. 1980; 8: 963. https://goo.gl/7S32oS
9. Hennemann, H. The subclavian vein - first-line acute dialysis access? Intensivmed.1978; 15: 236.
10. Bambauer R, P Mestres, KJ Pirrung. Frequency, therapy, and prevention of infections associated with large-bore catheters. ASAIO J. 1992; 38: 96-101. https://goo.gl/2hDcBk
11. Bambauer R, P Mestres, KJ Pirrung, R Inniger. Scanning electron microscopic investigations of large-bore catheters used for extracorporeal detoxification methods. Colloids and Surfaces A: Physicochemical and Engineering Aspects.1993; 77: 171-177. https://goo.gl/yvLdLt

12. Sioshansi P. New processes for surface treatment of catheters. Artif Organs. 1994; 18: 266-271. https://goo.gl/od49Kc

13. Bambauer R, P Mestres, KJ Pirrung, P Sioshansi. Scanning electron microscopic investigation of catheter for blood access. Artif Organs. 1994; 18: 272-275. https://goo.gl/wAqr8m

14. Bambauer R. Techniques for percutaneous puncturing of large vessels. In: Vascular Access for Blood purification methods and Catheter Technology. Bambauer R. (ed.).Wolfgang Pabst Verlag, Lengerich, Germany. 1991; 107-119.

15. Taylor G, JM Bone. A new silastic subclavian cannula for hemodialysis or plasma exchange. Dialysis & Transplantation. 1983; 12: 26.

16. Sioshansi P, EJ Tobin. Surface treatment of biomaterials by ion-beam processes. Med Plast Biomat. 1995. https://goo.gl/JVsVhx

17. Dathe G. Differentiation of different catheter materials according to shape, surface and function. therapy week. 1977; 27: 185.

18. Peters G, R Locci, G Pulverer. Microbiological colonisation of prosthetic devices. Scanning electron microscopy of naturally infected intravenous catheters. Zbl Bakt Hyg I Abt Orig. 1981; 173: 293. https://goo.gl/CD5K1S

19. Mestres P, K Rascher. Effects of monosodium glutamate on the development of intraventricular axons in the rat hypothalamus. Anat Embryol. 1983; 168: 433. https://goo.gl/6t8K3m

20. Bambauer R, P Mestres, R Schiel, P Sioshansi. New surface treatment technologies for catheters used for extracorporeal detoxification mehtods. Dialysis & Transplantation.1995; 24: 228. https://goo.gl/TaMMYd

21. Bambauer R, R Schiel, P Mestres. Scanning electron microscopic investigations of surface treated large-bore catheters used for extracorporeal detoxification methods. Int J Artif Org. 1995; 16: 326. https://goo.gl/cMbBDk

22. Bambauer R, M Austgen, W Mall, H Hartmann, UJ Uhl. Mediastinal hematoma - rare complication of internal jugular vein puncture. Intensivmed. 1980; 17: 232-235.

23. Bambauer R, GA Jutzler. Use of large-bore catheters in the internal jugular vein as an access route for emergency hemodialysis. Netherl J Surgery. 1983; 35-5: 178-183. https://goo.gl/HEdzX8

24. Bambauer R, P Mestres, KJ Pirrung. Raster-electron-microscopic investigations in large-bore catheters for extracorporeal detoxification. Int J Artif Organs. 1990; 13: 667-671. https://goo.gl/h4sHzj

25. Bambauer R, R Inniger, KJ Pirrung, R Schiel, R Dahlem. Complications and side effects associated with large-bore catheters in the subclavian and internal jugular vein. Artif Org. 1994; 18: 318-321. https://goo.gl/FFN5bh

26. Bambauer R, P Mestres, R Schiel, JM Schneidewind, R Goudinou, R Latza, et al. Surface treated large-bore catheters with silver based coatings versus untreated catheters for extracorporeal detoxification methods. ASAIO J. 1998; 44: 303-308. https://goo.gl/KBEVLj

27. Bambauer R, P Mestres, R Schiel, JM Schneidewind, R Latza, S Bambauer, et al. Surface treated catheters with Ion Beam based process for blood access. Therap Apher. 2000; 4: 342-347. https://goo.gl/1xtH31

28. Bambauer R, P Mestres, R Schiel, JM Schneidewind, S Bambauer, P Sioshansi. Large bore catheters with surface treatments versus untreated catheter for blood access. J Vascul Access. 2001; 2: 97-195. https://goo.gl/kqwyVM

29. Bambauer R, R Schiel, C Bambauer, R Latza: Surface-treated versus untreated large-bore catheters as vascular access in hemodialysis and apheresis treatments. Int J Nephrol. 2012; 2002: 956136. https://goo.gl/uRRF6P

30. Bambauer R, R Schiel, C Bambauer, R Latza. Surface treated catheters for vascular access – useful? Open J Nephrol. 2013; 3: 152-160. https://goo.gl/Wfg3uN

31. Bambauer R, R Latza. Complications in large-bore catheters for extracorporeal detoxification methods. Artif Org. 2004; 28: 629-633. https://goo.gl/KWNUsr

32. Strasheim W, MM Kock, V Ueckermann et al. Surveillance of catheter-related infections: the supplementary role of the microbiology laboratory. BMC Infectionous Diseases. 2015; 15: 5. https://goo.gl/9WQ1ek

33. Dababneh L, W Shomali, II Raad. Vascular catheter-related Infections. In: Infections in Hematology, Maschmeyer G, KVI Rolston (eds.) Springer, Berlin Heidelberg, 2015; 187-195. https://goo.gl/mhkw1T

34. Nielsen J, HJJ Kolosk, F Espersen. Staphylococcus aureus bacteremia among patients undergoing dialysis: focus dialysis catheter-related cases. Nephrol Dial Transplant. 1988; 13: 139-145. https://goo.gl/w9ACSx

35. Jean G, B Charra, C Chazot. Risk factor analysis for long-term tunnelled dialysis catheter-related bacteremias. Nephron 2002; 91: 399-405. https://goo.gl/KVS1PG

36. Kim SH, KI Song, JW Chang, Kim SB, Sung SA, Jo SK, et al. Prevention of uncuffed hemodialysis catheter-related bacteremia using an antibiotic lock technique: A prospective, randomised clinical trial. Kidney Int. 2006; 69: 161-164. https://goo.gl/5oD43L

37. King EA, D McCoy, S Desai et al. Vancomycin resistant enterococcal bacteraemia and daptomycin: are higher doses necessary? J Antimcicrob Chemother. 2011; 66: 2112-2118. https://goo.gl/JSUfHQ

38. Cui I, A Iwamoto, IO Lian, Neoh HM, Maruyama T, Horikawa Y, et al. Novel mechanism of antibiotic resistance originating in vancomycin-intermediate Staphylococcus aureus. Antimicrob Agents Chemother. 2006; 50: 428-438. https://goo.gl/Z2RwWE

39. Cui I, F Tominage, Neoh HM, Hiramatsu K. Correlation between reduced dantomycin suscentibility and vancomycin resistance in vancomycin-intermediate Staphylococcus aureus. Antimicrob Agents Chemother 2006; 50: 1079-1082. https://goo.gl/qVQ2Lm

40. Maki DG, Cobb L, Garman JK, Shapiro JM, Ringer M, Helgerson RB. An attachable silver-impregnated cuff for prevention of infection with central venous catheters: a prospective randomized multicenter trial. Am J Medical. 1988; 85: 307-314. https://goo.gl/ToZRZo

41. Tweden KS, JD Cameron, AJ Razzouk, Bianco RW, Holmberg WR, Bricault RJ, et al. Silver modification of polyethylene terphthalate textile for antimicrobial. ASAIO J. 1997; 43: 475-481. https://goo.gl/4qNj63

42. Oloffs A, C Gosse-Siestrup, S Bisson, Rinck M, Rudolph R, Gross U, et al. Biocompatibility of silver coated polyurethane catheters and silver coated Dacron material. Biomaterials. 1994; 15: 753-758. https://goo.gl/9gQeB8

43. Rabindranath KS, T Bansal, J Adams, Das R, Shail R, MacLeod AM, et al. Systematic review of antimicrobials for prevention of hemodialysis catheter-related infections. Nephrol Dial Transplant. 2009; 24: 3763-3774. https://goo.gl/jrBz8Q

44. Lai NM, N Chaivakunapruk,NA Lai et al. Catheter impregnation, coating or bonding for reducing central venous catheter-related infections in adults. Cochrane Database Syst Rev. 2016; 3: 7878. https://goo.gl/VDmcV6

45. Zhang L, JC Brownlie, C Rickard. Biofilms and intravascular catheter related bloodstream infections. In: The battle against microbial pathogens, basic sciences. Technological Advances and Educational Prognosis, (Mendes-Vilas, eds.) 2015; 405-412. https://goo.gl/6KKq2k

46. Hampton AA, RJ Sheretz. Vascular access infections in hospitalised patients. Surg Clin N Am. 1988; 68: 57-71. https://goo.gl/Na3wBh

47. Von Eif C, W Kohnen, K Becker. Modern strategies in the prevention of implant-associated infections. Int Artif Org. 2005; 28: 1146-1156. https://goo.gl/FPpQeb

48. Timsit JF, O Mimoz, B Mourviller, Souweine B, Garrouste-Orgeas M, Alfandari S, et al. Randomized controlled trial of chlorhexidine dressing and highly adhesive dressing for preventing catheter-related infections in critically ill adults. Am J Respir Crit Care Med. 2012; 186: 1272-1278. https://goo.gl/BsWbL9

49. Troidle L, FO Finkelstein. Catheter-related bacteremia in hemodialysis patients: The role of the central venous catheter in prevention and therapy. Int J Artif Org. 2008; 31: 827-833. https://goo.gl/SRnByn

50. Cicalini S, F Palmieri, N Petrosillo. Clinical review: New technologies for prevention of intravascular catheter-related infections. Crit Care. 2004; 8: 157-162. https://goo.gl/XCYjgQ

51. Donelli G, I Francolini, A Piozzi, Di Rosa R, Marconi W. New polymer-antibiotic systems to inhibit bacterial biofilm formation: a suitable approach to prevent central venous catheter-associated infections. J Chemother. 2002; 14: 501-507. https://goo.gl/7uGrmp

52. Schmitt S, G Haase, E Csomor, Lütticken R, Peltroche-Llacsahuanga H. Inhibitor of complement, Compstatin, prevents polymer-mediated Mac-1 up-regulation of human neutrophils independent of biomaterial type tested. J

Biomed Mater Res. 2003; 66A: 491-499. https://goo.gl/ncMeRS

53. Parsek MR, DL Val, BL Hanzelka, Brian L Hanzelka, John E Cronan Jr, E P Greenberg. Acyl homoserine-lactone quorum-sensing signal generation. Proc Natl Acad Sci USA. 1999; 96: 4360-4365. https://goo.gl/voM7hy

54. Davies DG, MR Parsek, JP Pearson, Iglewski BH, Costerton JW, Greenberg EP. The involvement of cell-to-cell signals in the development of a bacterial biofilm. Science. 1998; 280: 295-298. https://goo.gl/AzQYNd

55. Feldmann HJ, S Kobrin, A Wasserstein. Hemodialysis vascular morbidity. J Am Soc Nephrol. 1996; 7: 523-535. https://goo.gl/x4zjuX

56. Nakumara N, S Fukushima, T Hayakawa, Sekiya K, Matsumoto T. The additional costs of catheter-related bloodstream infections in intensive care units. Am J Infect Control. 2015; 43: 1046-1049. https://goo.gl/8N7bHQ

57. Bambauer R, Mestres P, Schiel R, Bambauer S, Sioshansi P, Latza R. Long-term catheters for Apheresis and dialysis with surface treatment with infection Resistance and low thrombogenecity. Therap Apher Dial. 2003; 7: 225-231. https://goo.gl/vw1Nm8

58. Bambauer S. Cost reduction benefits of applying an antimicrobial surface treatment to catheters. Personnel communication. 1996.

59. Schwebel C, JC Lucet, A Vesin. Economic evaluation of chlorhexidine-impregnated sponges for preventing catheter-related infection in critically ill adults in the Dressing Study. Crit Care Med. 2012; 40: 11-17. https://goo.gl/udCQrH

60. Pronovost PJ, CA Goeschel, E Colantuoni. Sustanining reductions in catheter-related bloodstream infections in Michigan intensive care units: observational study. Brit Med J. 2010; 340: 309. https://goo.gl/jtBhNe

61. Toccanelli E, G Smith, A Hiske, Lafuma A, Bastide P. Epidemiology, medical outcomes and costs of catheter-related bloodstream infections in intensive care units of four European countries: Literature- and registry-based estimates. Hospit Infect. 2009; 72: 97-103. https://goo.gl/mcc3oQ

62. Hollenbeck R, V Mickley, J Brunkwal. Vascular access for hemodialysis. Interdisciplinary recommendations of German medical societies. Nephrologe 2009; 4: 158-176. https://goo.gl/447Qbm

63. O´Grady NP, M Alexander, LA Burns, E. Patchen Dellinger, Jeffrey Garland, Stephen O. Heard, et al. Guidelines for the Preventions of Intravascular Catheter-related Infectiones. Clin Infect Dis 2011; 52; 162-193. https://goo.gl/bRkr23

64. Nagai T, S Kohsaka, T Anzai, Yoshikawa T, Fukuda K, Sato T. Low incidence of catheter-related complications in patients with advanced pulmonary arterial hypertension undergoing continuous epoprostenol infusions. Chest. 2012; 141: 272-273. https://goo.gl/a9pgcs

65. Ozden S, R Iscimen, H Akalin, N Kelebek Girgin, F Kahveci, M Sinirtas. Preventing catheter-related infections in ICUs: comparing care techniques. Crit Care. 2015; 19: 72. https://goo.gl/d6Px7n