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Review Article

Incidence and clinical implication of nosocomial infections associated with implantable biomaterials – catheters, ventilator-associated pneumonia, urinary tract infections

Inzidenz und klinische Folgen implantatassoziierter nosokomialer Infektionen – Blutgefäßkatheter, beatmungsassoziierte Pneumonie, Harnwegskatheter

Abstract

Health care associated infections, the fourth leading cause of disease in industrialised countries, are a major health issue. One part of this condition is based on the increasing insertion and implantation of prosthetic medical devices, since presence of a foreign body significantly reduces the number of bacteria required to produce infection. The most significant hospital-acquired infections, based on frequency and potential severity, are those related to procedures e.g. surgical site infections and medical devices, including urinary tract infection in catheterized patients, pneumonia in patients intubated on a ventilator and bacteraemia related to intravascular catheter use. At least half of all cases of nosocomial infections are associated with medical devices.

Modern medical and surgical practices have increasingly utilized implantable medical devices of various kinds. Such devices may be utilized only short-time or intermittently, for months, years or permanently. They improve the therapeutic outcome, save human lives and greatly enhance the quality of life of these patients. However, plastic devices are easily colonized with bacteria and fungi, able to be colonized by microorganisms at a rate of up to 0.5 cm per hour. A thick biofilm is formed within 24 hours on the entire surface of these plastic devices once inoculated even with a small initial number of bacteria.

The aim of the present work is to review the current literature on causes, frequency and preventive measures against infections associated with intravascular devices, catheter-related urinary tract infection, ventilator-associated infection, and infections of other implantable medical devices.

Raising awareness for infection associated with implanted medical devices, teaching and training skills of staff, and establishment of surveillance systems monitoring device-related infection seem to be the principal strategies used to achieve reduction and prevention of such infections. The intelligent use of suitable antiseptics in combination with medical devices may further support reduction and prevention of such infections. In addition to reducing the adverse clinical outcomes related with these infections, such reduction may substantially decrease the economic burden caused by device-related infection for health care systems.

Keywords: hospital-acquired infections, medical device associated infections, catheter related blood stream infections, ventilator-associated pneumonia, urinary tract infections, prosthetic joint infections, pace maker infections, vascular graft infections, prevention, surveillance

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Zusammenfassung

Nosokomiale Infektionen sind in industrialisierten Ländern heute die vierthäufigste Todesursache und schon allein deshalb eine große Herausforderung. Ein Teil des Problems geht auf die zunehmende Häufigkeit des Einsatzes invasiver Medizinprodukte (MP) zurück, da unter Anwesenheit eines MP eine signifikant geringere Anzahl von Mikroorganismen erforderlich ist, um eine Infektion zu begünstigen. Die häufigsten und häufig folgenschweren nosokomialen Infektionen sind postoperative Wundinfektionen sowie Infektionen im Zusammenhang mit eingesetzten oder implantierten MP wie Katheter-assoziierte Harnwegsinfektionen, Bakteriämien oder Beatmungs-assoziierte Pneumonien. Mindestens die Hälfte, wenn nicht weit mehr, dieser Infektionen sind mit dem Einsatz von MP vergesellschaftet. Moderne medizinische und chirurgische Behandlungsmethoden haben das Erfordernis des Einsatzes implantierbarer MP deutlich gesteigert. Dadurch sind große Fortschritte in den Behandlungsmöglichkeiten, in der Steigerung der Lebensqualität und in der Rettung von Patienten eröffnet worden. Solche MP können nur kurz, intermittierend, oder über Monate und sogar Jahre im Körper verbleiben. Werden sie mit Mikroorganismen kontaminiert, können diese das MP in einer Geschwindigkeit von bis zu 0,5 cm pro Stunde besiedeln. Als Folge können ausgehend von einer geringen initialen Kontaminationszahl schon innerhalb von 24 h dicke Biofilme entstehen, die die gesamte Fläche des MP einnehmen können.

Das Ziel der vorliegenden Übersichtsarbeit ist es, die bestehende Literatur hinsichtlich Ursachen, Häufigkeit, und präventiver Maßnahmen gegen MP-assoziierte Infektionen zu analysieren.

Gesteigerte Bewusstseinsbildung für den Zusammenhang zwischen implantierten MP und Infektionen, Schulung und Übung der Fertigkeiten hinsichtlich Umgang, sowie die Etablierung von Surveillance Systemen, die den Verbrauch und die mit MP vergesellschafteten Infektionen monitieren, scheinen die Eckpfeiler der Prävention MP-assoziierter Infektionen zu sein. Der Einsatz sinnvoll ausgewählter und richtig eingesetzter Antiseptika kann einen zusätzlichen Beitrag zur Reduktion MP-assoziierter Infektionen beitragen. Neben der Reduktion klinischer Nebenwirkungen kann die Reduktion MP-assoziierter Infektionen einen Beitrag zur Steigerung der Lebensqualität und Verbesserung der Behandlungsqualität leisten, aber auch zu signifikanten wirtschaftlichen Einsparungen im Gesundheitssystem beitragen.

Schlüsselwörter: Krankenhaus-erworbene Infektionen, Medizinprodukt-assoziierte Infektionen, Katheter-assoziierte Blutstrominfektionen, beatmungsassoziierte Pneumonie, Harnwegsinfektionen, Gelenkendoprotheseninfektionen, Herzschrittmacher-Infektionen, Gefäßprothesen-Infektionen, Prävention, Surveillance

Introduction

Health care associated infections, the fourth leading cause of disease in industrialised countries, are a major health issue. Such nosocomial (hospital-acquired) infections are today by far the most common complications affecting hospitalized patients. Based on a conservative estimate, 10% of the European population is hospitalised each year. Thereof, it is assumed that 5% (3.8% on a general ward, 15.3% in intensive care units) acquire at least one nosocomial infection. Based on these figures, it can be estimated that some 1.75 million hospitalised patients are affected annually in Europe. Assuming a conservative 10% attributable mortality rate, this equals 175,000 deaths from nosocomial infections every year [1]. The results of the EPIC study suggest even greater numbers of affected patients [2]. Reports from the US indicate that nosocomial infections accounts for 2 million infections and 90,000 deaths per year [3]. In 2000, the US Centers for Disease Control and Prevention estimated the total costs of nosocomial infections to be in excess of 5 billion US $. These figures do not take in account the vast cost of treating these infections and disabilities

caused by them [4]. In Germany, it is estimated that approximately 2.4 billion € are spent annually for treatment of these infections [5]. The impact on direct costs of medical care and the increase of healthy life condition together with loss of productivity due to early death or chronic illness has not been estimated [6].

While in Europe and developed countries the number of patients treated in hospitals and average lengths of stay decreased during recent decades, hospital acquired infections have increased. In addition, the consequences of hospital acquired infections have become more severe than a decade ago, also because of increasingly highly vulnerable patients together with emerging of antibiotic-resistant microbes, especially *Staphylococcus aureus, Enterococcus species* and Gram-negative microorganisms producing extended spectrum beta-lactamases (ESBL) [7], [8], [9]. The situation is getting even worse because in the next future there will be very few new antibiotics under development [10].

Health care providers, clinical epidemiologists, clinicians and hospital administrators are becoming increasingly concerned with the problem of preventable health care associated infections as infected medical devices are a common source of nosocomial infections and contribute to substantial morbidity and mortality. Crude mortality rates associated with nosocomial infections due to device-related infections vary from 12–80%, dependent on the population studies and the definitions used [11]. Attempts to assess attributable mortality rates are controversial since patients who need medical devices and develop nosocomial infections are generally sicker and have a greater risk of death than patients who do not [12]. Moreover, with the introduction of the diagnostic-related Groups system (DRGs) hospital acquired infections are generally not remunerable.

The most significant hospital-acquired infections, based on frequency and potential severity, are those related to procedures e.g. surgical site infections and medical devices, including urinary tract infection in catheterized patients, pneumonia in patients intubated on a ventilator and bacteraemia related to intravascular catheter use. At least half of all cases of nosocomial infections are associated with medical devices [13], [14], [15], [16]. It became clear since Elek and Conen demonstrated 1957 that the presence of a foreign body significantly reduces the number of bacteria required to produce infection [17]. Microorganisms gain access to the body by multiple pathogenetic pathways. They are significant both for their potential severity (illness and/or death), but also because of the potential preventability of these infections. Beside decreased patients' host defence and colonisation of mucous membranes by pathogenic microorganisms, the disruption of the integrity of the surface of the body caused by implantable medical devices and direct and indirect access of microorganisms into the respiratory tract, the urogenital tract, bloodstream and cerebrospinal space are major routes [18]. Despite the sometimes low virulence of invading microorganisms involved, the bodies own defence mechanisms are unable to eradicate the organisms effectively even when the host is fully immunocompetent. However, underlying disorders like malignancies, diabetes and agents impairing host defence mechanisms e.g. administration of corticosteroids, antineoplastic agents and parenteral nutrition are well recognized risk factors. Risk for nosocomial infections is, among others, associated with duration of hospital stay, type of ward and intensity of care [19], [20], [21], [22]. Multivariate analyses revealed that implantable medical devices as a major independent risk factor present on more than half of patients with positive blood cultures [15], [23].

Data from 498,998 patients analyzed in a report from the National Nosocomial Infection Surveillance (NNIS) system indicate that nosocomial urinary tract infections are among the most common causes of nosocomial infections, in 97% of cases associated with urinary catheters, 87% of primary bloodstream infections are associated with central lines [23]. As bacterial meningitis became a rare event during the last decade, ventriculitis and meningitis now are caused in more than 90% of patients due to external and internal implanted medical devices [24].

Modern medical and surgical practices have increasingly utilized implantable medical devices of various kinds. Such devices may be utilized only short-time or intermittently, for months, years or permanently. They improve the therapeutic outcome, save human lives and greatly enhance the quality of life of these patients. However, plastic devices are easily colonized with bacteria and fungi [24]. Multi-resistant nosocomial pathogens are the most common organisms colonizing the outer and inner surface of catheters and proliferate on the surface at a rate of up to 0.5 cm per hour. A thick biofilm is formed within 24 hours on the entire surface of these plastic devices once inoculated with a small number of bacteria [25].

The quoted incidence of nosocomial infection varies according to the medical device involved, the setting i.e. the type of hospital or intensive care unit, the population of patients the precise definition used [26].

Infections of intravascular devices

Vascular accesses are used for administration of fluids and electrolytes, blood products, medication, parenteral nutrition or haemodynamic monitoring. They are an essential tool of modern medicine. Regrettably, vascular access devices are also associated with substantial and generally underappreciated potential for producing iatrogenic disease, particularly bloodstream infection. In order to be able to compare the numerous clinical and epidemiological studies, definitions of the correct nomenclature of device related infections and type of infection is important [27], [28].

Local Infections

Foreign body related infections can be defined as local infection at the port of entry without signs of systemic

infection and must be distinguished from systemic infections i.e. bloodstream infections. However, not each isolation of a micro-organism from a catheter surface indicates a relevant infection requiring therapeutic attention. Colonization of medical devices without infection is possible.

Localized catheter colonization

Defines as significant growth of a microorganisms (>15 CFU) from the catheter tip, subcutaneous segment of the catheter or catheter hub. This has to be distinguished from local infections with clinical symptoms and signs of an inflammatory process.

Exit site infections

An erythema or induration within 2 cm of the catheter exit site is observed in absence of a concomitant bloodstream infection and without purulent discharge. Clinical exit site infection of tunnel infection means tenderness, erythaema or site induration >2 cm around the catheter site of along the subcutaneous tract of a tunnelled catheter in absence of a concomitant bloodstream infection.

Pocket infection

A pocket infection is defined as purulent discharge of the subcutaneous pocket of a totally implanted intravascular catheter that may or may not be associated with spontaneous rupture and drainage or necrosis of the overlying skin, in the absence of concomitant bloodstream infection.

Central venous catheter infections

Central venous catheters have been shown to be an important independent risk factor for nosocomial bloodstream infection (BSI) equivalent to septicaemia: In clinical studies, septicaemia is considered to be catheter associated when the pathogen, isolated from the catheter tip, the hub or the infusion solution is identical to the organism isolated in at least one peripheral blood culture. According to the definitions of the national nosocomial infection surveillance (NNIS) system of the CDC, bloodstream infections are always considered to be device related if there is a time link with the use of an i.v. catheter [4]. BSI is considered to be catheter associated if a central venous catheter (CVC) has been inserted 48 hours before the symptoms of infection occurred or if it is still in place [29].

Central venous catheters are indispensable in the management of critically ill patients, e.g. for administration of large amounts of fluids and electrolytes, drugs, parenteral nutrition and blood components. The history of central venous cannulation starts in 1929 when a young surgical resident inserted a cannula into his antecubital vein. By watching the catheter's progress in a mirror held in front of a fluoroscope screen, he passed it for 65 cm forward up to his auricle. By this maneuver the technique of vascular catheterization was developed [30]. Twenty-seven years later, in 1956, Werner Forssmann was awarded together with André Cournand and Dickson Richards, who put Forssmann's procedure 1941 into practice, the Nobel Prize.

In 1952 Aubaniac described his experiences of puncturing the subclavian vein. Since that time central venous catheterization has developed to a standard procedure in routine clinical practice [31]. In critical care and emergency medicine intravascular catheters have become integral to the practice of modern medicine.

However, while central venous catheters make intensive care for critically ill patients possible, they are also associated with serious complications, the most common of which is infection. Intravascular catheters are one of the most common causes of nosocomial bacteremia and catheter-related bloodstream infection affects over 250,000 patients per year in the United States [32]. The use of such devices account for an estimated 90% of all nosocomial bloodstream infections [33], and the attributable mortality in ICU patients is an estimated 35% for each infection [34].

Because of this, the decision to use central venous catheters must always be made on the basis of a strict risk-benefit assessment and for each patient the reasons for catheterization must be given careful consideration.

Central venous catheters: short term

Short term, non cuffed central venous catheters may become infected from multiple sources: The most obvious source of infection is the cutaneous origin of microorganisms that invade the percutaneous tract extraluminally at the time the catheter is inserted or the days following insertion – probably facilitated by capillary action [35], [36]. There is a strong concordance between organisms present on skin surrounding the catheter insertion site and organisms producing septicaemia. After the fourth day catheter contamination and BSI originates from the hub and the catheters are contaminated intralumenal [37]. With surgically implanted cuffed long-term Hickman or Broviac catheters, microorganisms colonizing the hub and lumen are the most important source of bloodstream infections. There is a substantial variable of bloodstream infections in multi-lumen catheters originating from different lumina: the large bore lumen with a flow of 100 ml/hour or more is the least likely lumen to be the source of a BSI although most frequently used for obtaining quantitative blood cultures. Small lumina with a flow rate of a few millilitres per hour, frequently used for administration of catecholamines which favour bacterial growth and biofilm formation are at a substantially higher risk for infection although infrequently used for blood cultures [38]. Antibiotics administered through one of the smaller lumina in contrast prevent contamination and infection [39].

A further source of infection is a contaminated infusate where large numbers of bacteria gain access intralumin-

ally. This route although rare is the most frequent route of an epidemic line related BSI [39]. Implantable devices can also become infected from remote unrelated sites of infection but evidence suggests that this is a rather uncommon cause of infection [40].

The incidence of catheter related sepsis is a matter of great controversy and substantial differences in incidence have been reported. Prospective studies of short term, non-cuffed single or multi-lumen catheters inserted percutaneously into the subclavian or jugular vein have found rates of catheter related septicaemia in a range of 3–5% with rates up to 14% in various hospitals. Risk factors for BSI are observed in patients with impaired host defence mechanisms e.g. premature and newborn infants, patients with severe burn injuries, diabetes, and corticosteroid treatment. In patients with haemato-oncologic malignancies a frequency of up to 16% of patients with device related BSI has been reported [41], [42], [43], [44], [45]. These vast differences can be attributed to the type of patient treated in an intensive care unit, the underlying disorders and drugs administered. It has to be emphasized that the duration of CVCs in this group of patients is generally longer [46]. A lower than average risk seems to be observed in patients receiving antibiotic for some indication [47]. However there is insufficient evidence from randomised trials to support or refute the use of prophylactic antibiotics when umbilical venous catheters are inserted in newborn infants. There is no evidence to support or refute continuing antibiotics once initial cultures rule out infection in newborn infants with umbilical venous catheters [48].

In paediatric intensive care units the incidence of catheter related BSI has been reported from 5.5/1,000 catheter days to 10.3/1,000 catheter days [48], [49], [50], [51]. In a survey performed in 74 paediatric intensive care units in the US a mean of 7.4/1,000 catheter days (range 1.3 and 11.9% of patients) has been observed. Higher rates have been reported in premature and newborn infants with 12.8/1,000 catheter days [52].

The source of the data is of crucial importance. Differences in incidence are seen between clinical prevention studies and data derived from surveillance studies. Differences in the incidence data are related to the type of study (prospective versus retrospective investigation) [53]. Surveillance data derived from 14% of hospitals of a country obtained by voluntary reporting can not legitimately extrapolated to the entire population. It has to be emphasized, that in field trials catheter associated BSI are substantially more frequent than commonly anticipated and described in literature. Data from all patients admitted to any Austrian intensive care unit during one half year have been collected by Hiesmayr et al. Their unpublished study involves 3,003 patients with a total of 29,473 device days and a mean of 9.81 catheter days. For central venous catheters an average of 6.9 infections/1,000 device days (6% of patients) have been observed by clinical criteria, 15.2/1,000 device days and 14.9% of patients by microbiologic criteria. Variations between 0 and 32/1,000 catheter days were observed in CVC. With arterial catheters an average of 2.4/1,000 catheter days was reported [54].

An increased incidence is seen with multi-lumen versus single lumen catheters, duration of catheter placement and the type of infusion solution i.e. physiological saline versus total parenteral nutrition containing amino acids and fat emulsions [55].

An important variable is also the number of manipulation at the hub, the fixation of the catheter and the dressing applied. Investigations have shown that consistent and high level of asepsis during catheter insertion and maintenance provided by special i.v. care teams have been associated with substantially lower rates of catheter related infections [56]. In accordance to this understaffing has also been identified as an independent risk factor [57].

Mortality attributed to CVCs ranges between 3 and 33% with an average of 20% [58], [59], [60], [61]. Again, these figures depend on a number of factors like the type of study, diagnosis and definition of the severity of nosocomial sepsis and the underlying disorders. Soufir et al. showed crude mortality rates of 50% and 21%, respectively, in patients with and without catheter related septicaemia and this figures remained valid with mortality adjusted for admission prognostic factors. However, when adjusted for severity scores measured during the week before infection, catheter related septicaemia was no longer associated with increased mortality [62].

Central venous catheters: intermediate (Sheldon)

Catheter-related infections have been identified as a major cause of morbidity and mortality in patients receiving haemodialysis independently in a number of studies [63], [64], [65]. There are particular risk factors originating from Sheldon catheters used for haemodialysis until maturation of a Cimino shunt. The mean duration of catheter placement is therefore with 6–12 weeks longer than the usual placement of short term CVCs. The double lumen catheter with a diameter maintaining a blood flow of at least 150 ml/min is placed into the jugular vein. There is generally a shorter subcutaneous tunnel and a stiffer material than used with short term central venous catheters. This enables easy penetration of microorganisms along the catheter path and also exerts damage to the great veins. Catheterization of the internal jugular vein is associated with longer catheter survival when compared to the femoral vein. The likelihood of catheter-related bacteraemia ranges between 2.1% and 48% at 6 months. The frequency of vascular access infection was 3.1 per 100 patient-months and varied from 0.6 for fistulas to 10.1/100 catheter days for temporary catheters [66]. Variable reporting systems are also a matter of discrepancies. Taylor et al. reported on the incidence of bloodstream infection in multi-centre inception cohorts of haemodialysis patients. A total of 527 patients were recruited and underwent 31,268 haemodialysis procedures during a 6-month follow-up. There were 96 blood-

stream infections in 93 patients indicating that 18% of patients suffered from a catheter related bloodstream infection (CRBI) (11.97/1,000 days, 28.81/1,000 haemodialysis procedures), yielding a relative risk of infection of 3.33 (95% CI, 2.12–5.24) for patients with a previous bloodstream infection and 1.56 (95% CI, 1.02–2.38) for patients on continuing haemodialysis [67]. Survival analysis revealed that compared to arterio-venous fistula vascular access, the relative risk of bloodstream infection in patients was 1.47 (95% CI, 0.36–5.96) for arterio-venous grafts, 8.49 (95% CI, 3.03–23.78) for cuffed central venous catheters, and 9.87 (95% CI, 3.46–28.20) for un-cuffed central venous catheters [68]. The regression model of the case-control study identified earlier bloodstream infection (6.58 d), poor patient hygiene (3.48 d), and superficial access-site infection (4.36 d) as additional risk factors. In general, the frequency of malfunction of a haemodialysis associated vascular device affects between 15 and 36% of patients.

The majority of cases requiring long-term continuous haemofiltration (CHF) are complicated with a variety of infections, it is difficult to control infections associated with haemodialysis catheters separately from infections of other types. Systemic infection control should serve as a strategy finally leading to successful control of catheter-related infection.

In a study conducted by Abdulrahman et al. a total of 109 infections, for a rate of 11.32/1,000 dialysis sessions were identified, 23 involved permanent fistulae or grafts (4.23/1,000); 18 involved permanent-tunnelled central catheter infections (10.1/1,000 dialysis); and 68 involved temporary-catheter infections (28.23/1,000 dialyses) [69].

Almost one quarter of population on haemodialysis remain catheter dependent. Despite concerted efforts, there are very long delays in achieving a usable permanent access in individual patients, attributable to delays in both surgical access placement and access maturation. An antibiotic lock of Sheldon-catheters in intervals between haemodialysis procedures has been shown to reduce the incidence of sepsis and increase the success of systemic antibiotic treatment of in line sepsis. The rate of vascular access infection is generally 3 per 100 patient-months and varies from 0.6 for fistulas to 10.1 for temporary catheters [70], [71], [72]. Prophylactic measures include antibiotic locks with various antibiotic regimens [73].

Peripheral venous catheters infections

At *peripheral venous catheters* catheter related phlebitis is a frequent problem. The rate of phlebitis varies in a broad range between 2.3 and 40%. The intravenous application of phlebitis-inducing medication and physiochemical and mechanical irritation of the vessel wall by various materials plays a major role and contributes to contamination with bacterial microorganisms. Steel needles are generally less well tolerated than small Teflon or polyurethane catheters now in use. Substantial improvements have been achieved with newer plastic materials regarding surface properties which have been identified to play a crucial role for thrombogenesis and infection [29].

High risk patients for infectious phlebitis were observed with haemato-oncologic malignancies [74]. An individual biologic vulnerability of individual patients has been found while the duration of placement of a peripheral catheter contributed less. An important factor was the level of technical skill for placement of peripheral catheters. Meticulous hygiene measures, less mechanical irritation and careful management by members of i.v. teams tend to have a lower incidence of phlebitis and infection than placement by less skilled personnel [75]. The choice of an optimal placement site is viewed controversial although placement in the lower extremity is connected with increased risk for thrombophlebitis and infection [76]. Bloodstream infections and positive bloodcultures are with 0.08%–0.2% a rather infrequent event in contrast to placement of a central venous catheter as an infected thrombus is frequently a local phenomenon [77], [78].

Infections caused by Tenckhof Catheters used for peritoneal dialysis

Peritoneal dialysis (PD) catheter insertion can be accomplished by any one of three techniques. These include dissective or surgical, the blind or modified Seldinger, and laparoscopic techniques. The dissective technique solely utilized by surgeons, places the catheter by mini-laparotomy under general anaesthesia. In the blind or modified Seldinger technique a needle is inserted into the abdomen, a guide-wire placed, a tract dilated and the catheter is inserted through a split-sheath, all without visualization of the peritoneal cavity [79]. Of the various laparoscopes, peritoneoscopic insertion uses a small optical peritoneoscope for direct inspection of the peritoneal cavity and identification of a suitable site for the intraperitoneal portion of the catheter. Hence, of the various techniques, only the insertion by direct pertoneoscopy allows the direct visualization of the intraperitoneal structures. This technique can be easily used by nephrologists as well as surgeons. Peritoneoscopic placement varies from traditional laparoscopic techniques by using a much smaller scope (2.2 mm diameter) and puncture size, only one peritoneal puncture site, a device to advance the cuff into the musculature, air in the peritoneum rather than CO_2, and local anaesthesia rather than general anaesthesia. Prospective randomized and nonrandomized studies have shown that peritoneal dialysis catheters peritoneoscopically placed by nephrologists have less incidence of complications (infection, exit site leak) and longer catheter survival rates than those inserted surgically [80], [81].

Boehm at al. reported an incidence of 1:14.6 months or 0.82/patient per year in children, indicating that more than every second patient was infected. Potential risk factors were significantly correlated with two or more of the outcome indices: age, APD treatment, exit-site infec-

tions, low urinary volume, low residual GFR and low nPCR [82]. Lerner et al. reported 964 episodes of peritonitis in 1,018 patient years, yielding an overall peritonitis rate of 1 episode every 13 patient months [72]. In contrast to this exceedingly high incidence Troidle et al. observed a frequency of 5%. Increased age, increased length of hospital stay, and hypoalbuminaemia may predispose patients to the development of nosocomial peritonitis [83]. In another study conducted by Bernardini et al. the frequency of peritonitis was 0.34/year versus 0.52/year (P=0.03) if patients received either gentamicin or mupirocin at the exit site [84]. Zelenitsky et al. reported 1.37 episodes/patient-year in 1991, which decreased to 0.55 episode/patient-year in 1998 (P=0.02). The frequency of Gram-positive peritonitis decreased significantly from 0.75 to 0.28 episode/patient-year during the same period (P=0.02). Conversely, the occurrence of Gram-negative peritonitis remained constant at approximately 0.16 episode/patient-year (P=0.28). *Staphylococcus epidermidis* and *Staphylococcus aureus* were the most common causes of peritonitis, isolated in 27.8% and 19.3% of the culture-positive cases, respectively [85].
Comparing peritonitis rates between older (0.95/year) and young (0.89/year) patients no differences were found. The older patients, however, had a higher frequency of *S. epidermidis* peritonitis (0.28/year vs. 0.13/year, p=0.0001). A study conducted by Chow et al. reports 85 initial episodes of peritonitis in 897.1 patient-years [86]. Levy et al. reviewed the clinical aspects of peritonitis in which 83 patients treated with continuous ambulatory or continuous cyclic peritoneal dialysis between May 1978 and April 1988 were analysed. Peritonitis occurred in 50 patients whose mean duration of dialysis was 17.8 months, but not in 33 patients with a mean duration of dialysis of 10.4 months. The mean time from starting dialysis to the first episode of peritonitis was 7.1 months. The peritonitis rate was lower for continuous cyclic than for continuous ambulatory peritoneal dialysis (1 episode per 12.9 vs. 1 episode per 8.1 patient months, respectively) [87].

Central venous catheters: long term (Hickman/Broviac type catheters [HB] catheters) and totally subcutaneously implantable medical devices (Port catheters [PAC])

Infectious complications are frequently encountered following tunnelled and cuffed long term Hickman-Broviac type catheter insertion [88]. The catheters are employed for application of antineoplastic medication in patients with haemato-oncologic malignancies or albumin infusions in patients with congenital nephrotic syndrome for several months. Data indicate that administration of parenteral nutrition is associated with a 2.5 fold increased risk of infection in children who have CVAD in place for cancer therapy. Also parenteral nutrition in patients with short bowel syndrome has a similarly increased risk for catheter associated infection [55], [89].
Investigations of the incidence of long term catheter related infections in large studies in an adult population indicate a rate of 0.7–1.2 per 1,000 catheter days. These figures may mislead the true incidence and the amount of problem as the catheters are in place for a minimum of 250 days. An average of 1 out of 4 patients will suffer from a catheter related septicaemia. In children with haemato-oncologic malignancies, frequencies of 2.15 infectious complications per 1,000 catheter days (1.4 for catheter insertion site and 0.75 bloodstream infections) have been reported [90], [91]. An infection rate of 1.9 per 1,000 catheter days has been reported by the ONCO KISS study in Germany relating to infections in 48% of patients [92]. Rosenthal and Maki compared totally implantable PORT catheters with Hickman catheters and showed a significantly higher infection rate with the Hickman catheter, 4.65 infections per 1,000 catheter days as compared to 1.45 episodes per 1,000 Port days, respectively [93]. Also, the time to first infection (52.3 days versus 108.82 days), a shorter duration of catheterization (140.75 versus 277.28 days) and hence a higher frequency of removal due to mechanical complications have been observed [91].
Haematopoetic stem cell transplantation was identified as an independent risk factor for infection (odds ratio –1.68). In another study, double-lumen (DL) or single-lumen (SL) Hickman-Broviac (HB) catheters, and single-lumen pressure-activated safety valve (PASV) catheters were used and prospectively evaluated. Four types of possible complication were defined: mechanical, thrombotic, malfunctioning and infectious. Four hundred and eighteen CVCs (180 single lumen -Hickman, 162 double lumen Hickman and 76 pressure-activated safety valve catheters) were inserted in 368 children, for a total of 107,012 catheter days at risk of complication. At least one complication occurred while using 169 of the devices (40%): 46% of the double lumen Hickman, 46% of the pressure-activated safety valve catheters and 33% of the single lumen Hickman (P=0.02) catheters. Patients with haematological malignancies or non-malignant diseases had significantly more complications than those with solid tumours (P <0.0001). Overall, 234 complications were documented: 93 infectious (complication rate per 1,000 catheter days at risk (CR)=0.87), 84 malfunctioning (CR=0.78), 48 mechanical (CR=0.45) and nine thrombotic (CR=0.08) episodes occured. Single lumen Hickman catheters had statistically fewer infectious complications, while pressure-activated safety valve catheters had more mechanical complications [94].
In Port-catheters the frequency of infection is considerably lower and rates of 0.08–0.71 have been reported [95]. Port catheters are infected mainly on the inside (80%). Pocket infection on the outside of the implantable device has been reported in 10% and on both in 10%. In a carefully conducted survey the average Port-catheters remained in situ for 232.9 (range 1–1298) days; the complication rate due to infections was reported to be

0.45/1,000 days of access. However, mechanical obstruction by thrombi, dislodgement of the catheter, ischemic necrosis of the overlying skin and soft tissues due an unfavourable design of the port chamber geometry and last not least perforation of the bottom of the port chamber have been observed [96]. In patients with Port-catheters a premature explantation of the device has to be performed in a substantial number of mainly paediatric patients [97]. Significant differences of premature explantation between Hickman/Broviac type and Port-catheters became evident at 400 days of catheter use. In spite of that totally implantable Port-catheters in general may be considered the preferred device for most paediatric oncology and stem cell transplantation patients. In general the Hickman-Broviac catheter and the totally implanted port Port-catheter achieve safe and reliable venous access in cancer patients [98].

Ventilator-associated pneumonia

Ventilator-associated pneumonia (VAP) is the most common nosocomial infection found in the intensive care unit with a reported incidence of 9% to 70% (average 20–25%) [15], [99], [100]. Data from a survey of all Austrian intensive care units observed an incidence of 25.7/1,000 device days [54]. It is associated with major morbidity, prolonged hospitalization, increased health care costs and a highest attributable mortality among all nosocomial infections ranging between 9–70% [101], [102], [103], [104]. The aero-digestive tract above the vocal cords is heavily colonized by bacteria; the lower respiratory tract is normally free of bacteria. The major route for acquiring VAP is the nasopharyngeal and oropharyngeal colonization by the endogenous flora or by pathogens acquired exogenously from the intensive care environment [105]. During critical illness and broad spectrum antibiotic coverage contaminated respiratory equipment or hospital water supply shifts the oral flora dramatically towards a predominance of multi-resistant Gram-negative bacilli and *S. aureus*. The stomach represents an additional potential site of secondary colonization and reservoir of nosocomial Gram-negative bacilli, when proton-pump inhibitors are used frequently.

Approximately 8 to 28% of patients receiving prolonged (>48 hours) mechanical ventilation will develop ventilator-associated pneumonia (VAP) [106]. Prior colonization of the aero-digestive tract is a common intermediary step in the pathogenesis of ventilator-associated pneumonia [107] and hence, a target for VAP prevention strategies. Moreover, colonization is also a key intermediary step in cross infection.

Considering many different kinds of evidence, there is no debate that VAP is associated with a higher risk of death than that due to the underlying disease alone, and new approaches to improve the management of ventilator-dependent patients are required. Therefore, studies in this field are needed to evaluate meaningful and effective interventions like effective prophylactic measures, earlier diagnosis and treatment.

Specific data on the epidemiology and pathogenesis of VAP are mainly limited by the lack of standardized criteria for its unequivocal identification and the absence of universally accepted standards continues the controversy about the adequacy and relevance of many studies on VAP. However, it has already been questioned ten years ago whether the study design itself may also influence the results of studies on VAP [108]. Back in 1995, the author conducted a meta-analysis to test the assumption, that intervention in a study population will eventually increase the rates of colonization and infection in a control population. The author demonstrated evidence that the possibility of cross-transmission, particularly transmission from intervention patients to control patients, exists in at least some of the controlled trials. Disparities between results of different studies in this field are explainable by a range of potential possibilities, cross-infection being one of them.

To investigate this finding more in depth, an ecological study would be needed. This task was performed only recently [109]. Using 42 cohort study groups as the reference standard, the prevalence of VAP was modeled in two linear regressions, one with the control groups and one with the intervention group of 96 VAP prevention studies. This ecological study revealed that the rate of VAP in the control groups of antibiotic prevention studies was significantly higher than expected and that the patterns of microbial isolates are unusual, suggesting the occurrence of not recognized outbreaks of VAP in these patients. The author concluded, that the possibility remains that antibiotic based VAP prevention presents a major cross infection hazard by the mechanism of selection and cross-transmission in ICUs. It also was concluded that being a control group of an antibiotic intervention study with a placebo design is correlated with an incidence of VAP above the expected. The implication of this finding would be that an influence of cross transmission in such designed studies is highly possible. Because this influence is inapparent in individual studies, conclusions drawn from such studies might not be correct and results of antibiotic prevention studies on VAP need to be re-examined.

However, this conclusion is problematic in view of antibiotic prevention or intervention studies. If an antibiotic is applied in the intervention group, selection and transmission of microorganisms is possible. However, it is inherent to this concept, that the selected organism itself will be resistant against the intervention compound, and hence, will colonize and/or infect both, patients in the intervention and control group. Therefore, the initial assumption might have no overall effect on the difference of incidence of VAP caused by a specific, resistant organism in two groups. In this respect it is not surprising that for in both groups the average residuals indicate an increase in incidence, contrary to the decrease suggested.

Endotracheal biofilm formation on the surface of a catheter plays a contributory role in sustaining nasotracheal

colonization [110]. The major normal defence mechanisms include anatomic airway barriers, cough reflexes, mucociliary clearance [111], [112]. Below the terminal bronchioles the cellular and humoral immune systems are essential components of host defence. Endotracheal intubation bypasses completely natural host defences as it suppresses the cough reflex, compromises mucociliary clearance, injures the tracheal epithelial surface and provides direct conduit for rapid access of bacteria from above into the lower respiratory tract [113]. Contaminated secretions pooled above the endotracheal cuff gain access to the trachea and inner lumen of the endotracheale tube by traversing endotracheale tube cuff folds [114]. Amorphic particulate containing pathogens is propelled into the distal airways by ventilator generated airflow or tubing manipulations. Dislodgement of contaminated biofilms by suction catheters has been suggested as additional pathway in which the respiratory tract may be inoculated. The combination of continuous exposure of the respiratory tract to large numbers of potential pathogens through the endotracheal tube and factors compromising host defence e.g. critical illness, co-morbidities such as chronic lung and heart diseases, malnutrition and the barotrauma through ventilatory support and immunosuppressive medication puts the mechanically ventilated patient at great jeopardy of developing VAP [115], [116], [117], [118].

Tracheotomy has been used in the ICU setting to facilitate weaning from the ventilator. Identical patho-mechanisms, however, are present in patients with tracheotomy [119]. The majority of studies investigating early or later tracheotomy indicate that the incidence of VAP is similar in both groups and tracheotomy is not able to prevent VAP. The presence of hyperthermia was identified as a risk factor for both early and late tracheotomy. The incidence of VAP in tracheotomised patients was 25.9% approximately 1 week after tracheotomy. However mortality seemed to be lower in the patients with tracheotomy [120].

In fact, VAP should be more accurately renamed endotracheal-tube-related-pneumonia as more than 85% of episodes of nosocomial pneumonia were associated with some sort of respiratory assistance device including endotracheale tubes, tracheotomy, nasal masks, nebulization treatment [95].

VAP is not the only source of endotracheal tube related nosocomial infection. Also nasotracheal intubation is a risk for the development of nosocomial sinusitis and contamination of the middle ear cavity. In a randomised trial conducted by Rouby at al it was observed that radiological sinusitis developed in 95% of patients intubated via the nasotracheal path compared to 23% with an oral tube [121], [122]. The entire tube is covered with a bacterial glycopolysaccharide revealing significant bacterial growth in the majority of tubes examined. These organisms are “milked” into the adjacent structure along the nasopharyngeal path of the endotracheale tube by continuous movement of the device with artificial respiration. The heavily contaminated mucous membranes act as a path for entry of pathogens into the systemic circulation. The incidence of bacteraemia and sepsis originating from the upper airways ranges between 12 and 18%.

A number of preventive measures have been designed taking the described pathomechanisms into account. There is preference of orotracheal versus nasotracheal intubation, the use of non-invasive ventilation, and the use of endotracheal tube with a dorsal lumen to allow drainage or continuous subglottic suctioning of pooled secretions above the cuff [123]. Strategies eradicating the oropharyngeal and/or intestinal microbial colonization such as chlorhexidine oral care, prophylactic aerosolization of antimicrobials, selective aerodigestive mucosal antimicrobial decontamination or the use of sucralfate rather than H_2 antagonists for stress ulcer prophylaxis as well as measures to prevent aspiration by a semi-recumbent positioning have been shown to reduce the risk to some degree in independent studies [124], [125]. Needless to say that hospital water has to be controlled for *Legionella pneumophilia*. The use of medical devices endowed with antimicrobial activity has not been investigated yet fully but promising results could be expected [126].

Nosocomial urinary tract infections

A urinary tract infection (UTI) is a condition where one or more structures in the urinary tract become infected after bacteria overcome its strong natural defenses. In spite of these defenses, UTIs are the most common of all infections and can occur at any time in the life of an individual. Infections of the urinary tract are the second most common accounting for 8–35% of all nosocomial infections [15]. Millions of transurethral, suprapubic and nephrostomy catheters or uretheral stents are used each year. This device subverts several host defences to allow bacterial entry at a cumulative rate of 3% to 10% per day i.e. after 1 month all patients suffer from a bacteriuria [127]. Most frequently, bacteria from the urethral meatus ascend to the bladder between the mucosal and catheter surfaces. Alternatively, bacteria may ascend within the drainage system following contamination of the drainage bag or disruption of the catheter tubing junction. The presence of an implantable device encourages the organism's persistent residence in the urinary tract. Catheter-associated urinary tract infections are a frequent cause of significant morbidity. Nosocomial urinary tract infections are closely linked to unalterable host factors such as age, female sex, and debilitating disease. There are also dietary factors affecting the susceptibility to urinary tract infection by alteration of the bacterial composition of stool or alkalinization of the urine favoring struvite formation [128].

The consequences of nosocomial urinary tract infections are generally less severe than for other types of nosocomial infections and catheter-associated bacteriurias are frequently asymptomatic. The complications in short-term catheterized patients include fever, acute pyelonephritis,

bacteraemia; patients with long-term catheters in place are at risk for these complications with catheter obstruction, urinary tract stones, local periurinary infections, chronic renal inflammation, chronic pyelonephritis, and, over years, bladder cancer. The prolongation of duration of admission is generally 3 days [129], [130], [131].
Risk factors for bacteriuria are

- Duration of catheter placement >14 days
- No systemic antibiotics
- Female gender, age >65
- Serum Kreatinin >2 mg/dl
- Diabetes mellitus
- Severe, rapidly fatal underlying disorder
- Lack of aseptic techniques during catheter placement
- Contamination of collecting bag
- Periurethral contamination with pathogenic microorganisms

Recent attention has appropriately focused on biofilm formation by urea forming microorganisms on the catheter surface because biofilm and hence the incrustation with calcium and magnesium struvites has important implications for the pathogenesis, treatment, and prevention of catheter-related infection.
Sepsis (4%) is predominately seen with obstruction of an indwelling transurethral catheter and results in a mortality of 13% [132]. Risk factor for nosocomial bacteraemia and sepsis originating in the urinary tract are

- Male gender, age >65 a
- Infection with *Serratia marcescens*
- Non-infectious disorders of the urinary tract (Nephrolithiasis, Prostata Ca)

Transurethral catheterization is generally associated with a higher incidence of urinary tract infections than suprapubic catheterization; however, suprapubic catheterization is associated with other disadvantages such as higher costs and a more difficult technique, and at the moment there is no consensus about the use of both catheter systems [133]. There is no difference in the incidence of a urinary tract infection between the suprapubic group (n=9/75; 12%) and the transurethral group (n=8/71; 11%) [134]. The incidence of a urinary tract infection between a suprapubic catheter and a transurethral catheter in patients undergoing major surgery was not different. A potential advantage of the suprapubic catheter (reduction of urinary tract infections) is probably partly negated, because transurethral catheters were used if re-catheterization was indicated during the postoperative stay or due to complications.
Preventive measures for nosocomial urinary tract infections have been investigated. Systemic antibiotics have not been effective. Their use results in infection of the bladder with resistant organisms, including *Candida sp.* [135]. This and the effect of side effects on the patient and emergence of resistant bacteria in the medical unit have led most authorities to conclude that antibiotics are not useful for prevention of bacteriuria, nor for treatment of bacteriuria in the asymptomatic catheterized patient.
The closed catheter system has been a magnificent step forward in the prevention of catheter-associated bacteriuria. Indeed, only two catheter principles are universally recommended: keep the closed catheter system closed and remove the catheter as soon as possible [136]. Most modifications of the closed catheter system have not improved markedly on its ability to postpone bacteriuria. Prevention of postoperative bacteriuria must be based on careful haemostasis, prevention of postoperative catheter disconnections, and limitation of the duration of postoperative catheterization. The frequency of postoperative bacteriuria after transurethral resection of the prostate is raising the question of the choice and/or duration of prophylactic antibiotics. Antimicrobial prophylaxis frequently leads to outgrowth of resistant bacterial strains that are difficult to eradicate. However, antimicrobial prophylaxis warrants consideration for high-risk immunocompromised patients who are catheterized for a short time. If bacteriuria occurs prior to removal of the catheter, the patient should be treated with appropriate antimicrobial therapy.

Infections of other implantable medical devices

External and internal ventricular drainage systems

Since four decades, neurosurgeons have inserted prosthetic devices into the central nervous system [137], [138]. Drainage systems are either implanted for diversion of cerebrospinal fluid in patients with hydrocephalus but also for emergency treatment of an increased intracranial pressure. A second major indication for insertion of a CNS prosthetic device is continuous intracranial pressure monitoring. This and external ventricular drainage systems in critically ill patients are of particular concern because of the threat they pose to cerebral function. External drainage and pressure monitoring systems, to lesser degree internal CSF shunts may lead to ventriculitis, meningitis and ventricular compartmentalisation. CNS infections are complicated by deterioration of mental capacity and can also be especially lethal [139].
Difficulties arise as the offending organisms are frequently multi-resistant nosocomial pathogens for which only a limited spectrum of antibiotics substances is active. Antibiotics like glycopeptides and aminoglycosides do not penetrate the blood-brain barrier in bactericidal concentrations [140].
The frequency of infected external ventricular drainage systems is in a range between 6 and 15% with a mean of 12%. Studies have demonstrated that prophylactic antibiotic e.g. quinolones do not reduce the incidence of device related infections [141].

Prosthetic joint infections

Prosthetic joint implantation is among the most remarkable advances in surgery to occur during the last decade. However, because of the devastating results and large number of prosthetic procedures, prosthetic infection remains a major challenge. Although the results of this procedure are usually highly satisfactory, infection is recognized as a serious cause of postoperative morbidity and prosthesis failure. Infections of the prosthesis occurs only in a small proportion of patients, however, this dreaded complication results in major morbidity due to pain, lifetime bedridden, failure and loss of prosthesis, requirement of re-operation and in some instances loss of limb or life [142], [143], [144]. Successful treatment is difficult and usually requires both, multiple operative procedures and antimicrobial therapy in excess of three months [145]. In spite of these measures, the therapeutic outcome is less than satisfactory.

Two major mechanisms by which microorganisms cause prosthetic joint infections have been postulated. Microorganisms may colonize the prosthesis at the time of implantation either through direct inoculation or as a result of airborne contamination of the wound or device [146]. Alternatively, microorganisms may reach a previously sterile implant either through haematogenous seeding during a bacteraemia or from an adjacent focus of infection [147]. The distinction between the two mechanisms may be difficult due to the long latency period between onset of infection and the appearance of symptoms. Despite this controversy it is believed hat the majority of prosthetic joint infections are acquired in the operating room.

Adoption of advanced methods for clinical and microbiologic diagnosis and effective prophylactic measures such as improved operating room techniques and systemic antibiotics, the prosthetic infection rate for artificial joint procedures has been favourably influenced [148]. Advances in regard to the prediction of a successful antimicrobial therapy have been achieved [149]. Prosthetic joint infections occur in approximately 1.5%–2.5% of all primary hip or knee arthroplasties. The mortality rate attributed to prosthetic joint infection may be as high as 2.5% [150]. Advanced age is one of the greatest a risk factors for prosthetic joint infection as well a underlying disorders such as rheumatoid arthritis; corticosteroid treatment, diabetes mellitus and malignancies. In patients older than 80 years of age an incidence of 9.5% has been reported. Haemophilia, in contrast, was identified as a single independent risk factor in 16% of affected patients. Rheumatoid arthritis may be a risk factor for late prosthetic joint infections in older prosthetic joint patients undergoing invasive dental procedure in the posterior oral cavity [151], [152]. Fife infected prosthetic joints have been reported in 4,010 joint years of HIV positive patients, and HIV seemed to be no predisposing factor [153]. A previous history of septic arthritis or osteomyelitis has been identified as independent risk factor.

The treatment of an already infected prosthetic joint is difficult. Debridement and retention of the prosthesis is the initial treatment modality. This has been performed in 30 patients with 33 *Staphylococcus aureus* prosthetic joint infections who presented to the Mayo Clinic between 1980 and 1991. Treatment failure, defined as relapse of *S. aureus* prosthetic joint infection or occurrence of culture-negative prosthetic joint infection during continuous anti-staphylococcal therapy, occurred in 21 of 33 prosthetic joints [154]. The overall infection rate (when late sepsis up to an observation period of 4 years is included) remains at over 1%, and will likely increase as the life expectancy of implants is increased and patients are followed up longer. Data from Spain report an incidence of 5.1% [155]. However, the sole correction using ASA scoring led to an uncorrected SSI frequency of 5.8 per 100 surgeries. In the NNIS risk group 0 using corrected ASA scores, the frequency was 4.5 per 100 surgeries [156].

An early diagnosis may sometimes be difficult due to lack of significant inflammatory signs. Low-grade infections in particular are difficult to distinguish from aseptic failure, often presenting only with early loosening and persisting pain, or no clinical signs of infection at all. The most favoured approach is the two-stage delayed re-implantation, in which patients receive specific antibiotic therapy for 6 weeks or more. Several additional antibiotics other than vancomycin are available for methicillin-resistant staphylococcal infection, but these are still unproven in the treatment of osteomyelitis or prosthetic joint infection [157].

Pacemaker Infections

The implantation of a pacemaker has become an everyday medical procedure. New indications are under evaluation. However, it should be recalled that this is a surgical intervention with implantation of prosthesis with possible complications [158]. There are early complications which occur in the first 6 weeks after implantation and late complications. Their over all incidence is underestimated (up to 7%) as well as their seriousness [159]. The reported incidence of pacing system-related infections varies widely, and the roles of leads and blood cultures remain poorly defined. During the previous decade, there was a significant increase in both, cardiac device implantations, and infections in elderly patients, although the increase in the frequency of device infections was substantially higher. The incidence of end point events in control groups ranged from 0% to 12%. The meta-analysis suggested a consistent protective effect of antibiotic pretreatment ($P=.0046$; common odds ratio: 0.256, 95% confidence interval: 0.10 to 0.656). This incidence was significantly higher than in patients younger than 40 years at first implantation without congenital heart disease (2.3%) and in patients older than 40 years (1.2%, $P<0.001$) (5%) [160]. The majority of pacemaker infections are responsible for pacemaker dysfunction, the risk of which is proportional to the dependence of the patient

on permanent cardiac pacing [161]. The overall incidence of late complications was significantly lower after first implantation of a permanent pacemaker (34 cases, complication rate 1.4%, 95% confidence interval 0.9% to 1.9%) than after elective unit replacement (16 cases, complication rate 6.5% (3.3% to 9.7%) [162], [163]. The highest incidence of device related infection was in heart transplant recipients with 20% [164], [165].

Pacemaker endocarditis is a rare but serious complication [166]. Clinical characteristics and outcome were retrospectively studied in 38 patients with 44 episodes of pacemaker infective endocarditis in Goteborg, during 1984–2001. Transthoracic echocardiography showed vegetation in 4/22 (18%) episodes and transoesophageal echocardiography in 22/33 (67%). Staphylococci were isolated in 66% of blood cultures. Overall mortality was 24% after a mean follow-up period of 22 +/- 4 months (range 1 to 88) [167]. The frequency of prosthetic infective endocarditis varies according to the criteria used in the literature, ranging from 0.4 to 1.3% for early infective endocarditis, with an annual linear risk of late infective endocarditis of 0.5% [168].

Regardless of the clinical presentation, the extravascular and intravascular body of the lead is infected, even when the infection is local. More than one micro-organism may be implicated. Bacteriologic analyses must be performed on several segments of each implanted lead. More than 2 positive blood cultures are a reliable clinical criterion for the diagnosis of pacemaker lead-related infection, but blood cultures alone are an insensitive method to identify the cause of infection. Up to 50% of microorganisms isolated in a single blood culture are also recovered in lead cultures. Recurrent undiagnosed septic pulmonary embolisms from pacemaker lead vegetations inducing chronic cor pulmonale with serious pulmonary arterial hypertension [169].

Vascular graft infections

Technological advances in artificial conduits have made vascular reconstructive surgery to any accessible artery possible [170]. While infection rates for autologous venous and arterial grafts is low, there is a substantial increase of infections in synthetic grafts with devastating complications including sepsis, anastomotic disruption with mass haemorrhage and pseudoaneurysm formation, graft thrombosis limb loss and high perioperative and late mortality [171], [172]. Infra-inguinal arterial prosthetic graft is associated with substantial early mortality and amputation rates [173]. Cryopreserved arterial allograft in the management of major peripheral bypass graft infection suggests that this technique seems to be a useful option for treating one of the most dreaded vascular complications [174].

In a comprehensive survey 410 revascularization procedures (84 aortic, 41 extraanatomic, and 285 infrainguinal) were performed in patients with a mean age of 62 years (range 43–88). The infection rate for the entire group was 11.0% (45/410). Eighty percent (36/45) occurred after infra-inguinal reconstructions and 64% (29/45) of the infections involved the groin incision [175]. In a further investigation in a smaller number of patients pathomechanisms were studies: direct involvement of the graft occurred in 67% (30/45), and 27% (12/45) presented with anastomotic disruption [176]. The overall mortality rate was 13 of 23 (56.5%) patients. The allograft-related mortality rate was 5 of 23 (22%). The overall allograft-complicated patient rate was 15 of 23 (65%); and 18 allograft ruptures in 12 patients and 8 allograft thromboses in 6 patients were observed. The overall amputation rate was 8.7% (2 of 23). Age of the recipient older than 69 years (P=.02), positive preoperative marked-leukocyte scanning (P=.04), and persistent postoperative leukocytosis (P=0.03) were significant variables associated with an increased risk of allograft-related complications [177]. The rate however varies considerably, optimal surgical techniques and perioperative antibiotic prophylaxis seemed to stabilise the rate at 1–5% [178]. During the last years the situation has been complicated by the increased emergence of multiresistant microorganisms e.g. MRSA accounting now for up to approximately 30% of clinical *S. aureus* isolates.

Special risk factors for this complication included malnutrition, ongoing polymicrobial and fungal infections, immunocompromised state, active cancer, steroid treatment, and ongoing graft contamination from gastrointestinal or pharyngeal leaks [179]. Risk factors for sepsis after vascular surgery are substantially more frequent in patients with lower limb arterial ischemia. Pathogenic organisms were isolated from the skin preoperatively significantly more frequently in patients with ischemic rest pain and skin necrosis (66%) than rest pain alone (21%) (P=0.0004) or claudication/aneurysm (11%) (P=0.0001) [180].

Dacron and polytetrafluorethylene (GoreTex) are the synthetic graft materials best suitable. The heparin-bonded ePTFE graft provided promising early patency and limb salvage results, with no device-related complications, in patients with occlusive vascular disease. Longer-term and randomized studies are warranted to determine whether this graft provides results superior to those achieved with other prostheses, especially in patients at increased risk of early graft failure. Further improvements e.g. with addition of silver nanoparticles are still possible [181], [182].

Discussion

As noted in a position paper published in 2005 [1] ESCMID is seriously concerned about the fact that although it has been known for many years that antibiotic resistance is becoming an increasing problem, there are very few new antibiotics under development. The survey of infection rates of various implantable biomaterials indicates that this factor accounts for the majority of nosocomial infections and must be considered an independent risk factors. Certainly, additional factors e.g. prematurity

or old age, underlying disorders impairing host defence mechanisms e.g. neutropenia, diabetes mellitus, haemophilia, end stage renal disease and the administration of certain drugs such as corticosteroides, and other immunosuppressants.

The diagnosis of device related infections sometimes is difficult. Diagnosis can also be suggested by the presence of a predisposing factor, febrile illness, and seemingly unrelated underlying disorders. Even with problems not directly suggestive of sepsis associated with implantable biomaterial a device associated infection must be taken into consideration. Variable and often non-specific clinical and radiographic features of multiple, nodular infiltrates in the lung are found in septic pulmonary embolism (SPE), an uncommon disorder with an insidious onset and a difficult diagnosis. Underlying condition predisposing for SPE in a study with 14 patients included Lemmieres syndrome (4/14), central venous catheter associated infection (3/14) prosthetic cardiac valve infection ((2/14) and pacemaker infection (2/14) [183].

The establishment of an infection control network within a group of community hospitals was associated with substantial decreases in nosocomial infection rates. Standard surveillance methods, frequent data analysis and feedback, and interventions based on guidelines and protocols from the Centers for Disease Control and Prevention were the principal strategies used to achieve these reductions. In addition to lessening the adverse clinical outcomes due to nosocomial infections, these reductions substantially decreased the economic burden of infection: the decline in nosocomial bloodstream infections and ventilator-associated pneumonia alone yielded potential savings of $ 578,307 to $ 2,195,954 per year at the study hospitals [184].

Notes

Conflicts of interest

The authors declare that they have no competing interests.

References

1. Report of the European Science Foundation. Available from: http://www.escmid.org/ September 1, 2005
2. Vincent JL, Bihari DJ, Suter PM, Bruining HA, White J, Nicolas-Chanoin MH, Wolff M, Spencer RC, Hemmer M. The prevalence of nosocomial infection in intensive care units in Europe. Results of the European Prevalence of Infection in Intensive Care (EPIC) Study. EPIC International Advisory Committee. JAMA. 1995;274(8):639-44. DOI: 10.1001/jama.274.8.639
3. Ecker DJ, Carroll KC. Investments in high payoff technologies could reduce toll of infections. ASM News. 2005;71(12):576-581.
4. Nosocomial infection rates for interhospital comparison: limitations and possible solutions. A Report from the National Nosocomial Infections Surveillance (NNIS) System. Infect Control Hosp Epidemiol. 1991;12(10):609-21.
5. Frank U, Chojnacki T, Dettenkofer M, Daschner FD. Cost-effectiveness of an antiseptic-impregnated central venous catheter in the ICU. Intensive Care Med. 2003;29(1):139.
6. Digiovine B, Chenoweth C, Watts C, Higgins M. The attributable mortality and costs of primary nosocomial bloodstream infections in the intensive care unit. Am J Respir Crit Care Med. 1999;160(3):976-81.
7. Legras A, Malvy D, Quinioux AI, Villers D, Bouachour G, Robert R, Thomas R. Nosocomial infections: prospective survey of incidence in five French intensive care units. Intensive Care Med. 1998;24(10):1040-6. DOI: 10.1007/s001340050713
8. Raad II, Hanna HA, Boktour M, Jabbour N, Hachem RY, Darouiche RO. Catheter-related vancomycin-resistant Enterococcus faecium bacteremia: clinical and molecular epidemiology. Infect Control Hosp Epidemiol. 2005;26(7):658-61. DOI: 10.1086/502598
9. Chu VH, Crosslin DR, Friedman JY, Reed SD, Cabell CH, Griffiths RI, Masselink LE, Kaye KS, Corey GR, Reller LB, Stryjewski ME, Schulman KA, Fowler VG Jr. Staphylococcus aureus bacteremia in patients with prosthetic devices: costs and outcomes. Am J Med. 2005;118(12):1416. DOI: 10.1016/j.amjmed.2005.06.011
10. Norrby SR, Nord CE, Finch R; European Society of Clinical Microbiology and Infectious Diseases. Lack of development of new antimicrobial drugs: a potential serious threat to public health. Lancet Infect Dis. 2005;5(2):115-9.
11. Smith RL, Meixler SM, Simberkoff MS. Excess mortality in critically ill patients with nosocomial bloodstream infections. Chest. 1991;100(1):164-7. DOI: 10.1378/chest.100.1.164
12. Kollef MH, Shorr A, Tabak YP, Gupta V, Liu LZ, Johannes RS. Epidemiology and outcomes of health-care-associated pneumonia: results from a large US database of culture-positive pneumonia. Chest. 2005;128(6):3854-62. DOI: 10.1378/chest.128.6.3854
13. Collignon PJ. Intravascular catheter associated sepsis: a common problem. The Australian Study on Intravascular Catheter Associated Sepsis. Med J Aust. 1994;161(6):374-8.
14. Richards MJ, Edwards JR, Culver DH, Gaynes RP. Nosocomial infections in medical intensive care units in the United States. National Nosocomial Infections Surveillance System. Crit Care Med. 1999;27(5):887-92. DOI: 10.1097/00003246-199905000-00020
15. Vincent JL. Nosocomial infections in adult intensive-care units. Lancet. 2003;361(9374):2068-77. DOI: 10.1016/S0140-6736(03)13644-6
16. Safdar N, Crnich CJ, Maki DG. Nosocomial Infections in the Intensive Care Unit Associated with Invasive Medical Devices. Curr Infect Dis Rep. 2001;3(6):487-495. DOI: 10.1007/s11908-001-0085-5
17. Elek SD, Conen PE. The virulence of Staphylococcus pyogenes for man; a study of the problems of wound infection. Br J Exp Pathol. 1957;38(6):573-86.
18. Lorente L, Henry C, Martín MM, Jiménez A, Mora ML. Central venous catheter-related infection in a prospective and observational study of 2,595 catheters. Crit Care. 2005;9(6):R631-5. DOI: 10.1186/cc3824
19. Yoshida T, Tsushima K, Tsuchiya A, Nishikawa N, Shirahata K, Kaneko K, Ito K, Kawakami H, Nakagawa S, Suzuki T, Kubo K, Ikeda S. Risk factors for hospital-acquired bacteremia. Intern Med. 2005;44(11):1157-62. DOI: 10.2169/internalmedicine.44.1157
20. Beghetto MG, Victorino J, Teixeira L, de Azevedo MJ. Parenteral nutrition as a risk factor for central venous catheter-related infection. JPEN J Parenter Enteral Nutr. 2005;29(5):367-73. DOI: 10.1177/0148607105029005367

21. Raymond J, Aujard Y. Nosocomial infections in pediatric patients: a European, multicenter prospective study. European Study Group. Infect Control Hosp Epidemiol. 2000;21(4):260-3. DOI: 10.1086/501755

22. Kaech C, Elzi L, Sendi P, Frei R, Laifer G, Bassetti S, Fluckiger U. Course and outcome of Staphylococcus aureus bacteraemia: a retrospective analysis of 308 episodes in a Swiss tertiary-care centre. Clin Microbiol Infect. 2006;12(4):345-52. DOI: 10.1111/j.1469-0691.2005.01359.x

23. National Nosocomial Infections Surveillance System. National Nosocomial Infections Surveillance (NNIS) System Report, data summary from January 1992 to June 2002, issued August 2002. Am J Infect Control. 2002;30(8):458-75. DOI: 10.1067/mic.2002.130032

24. Locci R, Peters G, Pulverer G. Microbial colonization of prosthetic devices. IV. Scanning electron microscopy of intravenous catheters invaded by yeasts. Zentralbl Bakteriol Mikrobiol Hyg B. 1981;173(6):419-24.

25. Chambless JD, Hunt SM, Stewart PS. A three-dimensional computer model of four hypothetical mechanisms protecting biofilms from antimicrobials. Appl Environ Microbiol. 2006;72(3):2005-13. DOI: 10.1128/AEM.72.3.2005-2013.2006

26. Garner JS, Jarvis WR, Emori TG, Horan TC, Hughes JM. CDC definitions for nosocomial infections, 1988. Am J Infect Control. 1988;16(3):128-40. DOI: 10.1016/0196-6553(88)90053-3

27. Horan TC, Emori TG. Definitions of key terms used in the NNIS System. Am J Infect Control. 1997;25(2):112-6. DOI: 10.1016/S0196-6553(97)90037-7

28. Hiramatsu K, Nasu M. [Intravascular device-related infection]. Nihon Rinsho. 2002;60(11):2107-11.

29. Szycher M. Biostability of polyurethane elastomers: a critical review. J Biomater Appl. 1988;3(2):297-402. DOI: 10.1177/088532828800300207

30. Forssmann WTO. Die Sondierung des rechten Herzens. Klin Wschr. 1929;8:2085-7. DOI: 10.1007/BF01875120

31. Aubaniac R. L'injection intraveineuse sosclaviculaire, advantages et technique [Subclavian intravenous injection; advantages and technic]. Presse Med. 1952;60(68):1456.

32. Safdar N, Kluger DM, Maki DG. A review of risk factors for catheter-related bloodstream infection caused by percutaneously inserted, noncuffed central venous catheters: implications for preventive strategies. Medicine (Baltimore). 2002;81(6):466-79. DOI: 10.1097/00005792-200211000-00007

33. Donelli G, Francolini I. Efficacy of antiadhesive, antibiotic and antiseptic coatings in preventing catheter-related infections: review. J Chemother. 2001;13(6):595-606.

34. Maki DG. Infections caused by intravascular devices used in infusion therapy: pathogenesis, prevention, and management. In: Bisno AL, Waldvogel FA, eds. Infections Associated With Indwelling Medical Devices. 2nd ed. Washington, DC: ASM Press; 1994. P. 155-212.

35. Maki DG. Infections due to infusion therapy. In: Bennett JV, Brachman PS, eds. Hospital Infections. 3d ed. Boston: Little, Brown; 1992.

36. Elliott TS, Moss HA, Tebbs SE, Wilson IC, Bonser RS, Graham TR, Burke LP, Faroqui MH. Novel approach to investigate a source of microbial contamination of central venous catheters. Eur J Clin Microbiol Infect Dis. 1997;16(3):210-3. DOI: 10.1007/BF01709583

37. Sitges-Serra A, Linares J, Garau J. Catheter sepsis: the clue is the hub. Surgery. 1985;97(3):355-7.

38. Lyte M, Freestone PP, Neal CP, Olson BA, Haigh RD, Bayston R, Williams PH. Stimulation of Staphylococcus epidermidis growth and biofilm formation by catecholamine inotropes. Lancet. 2003;361(9352):130-5. DOI: 10.1016/S0140-6736(03)12231-3

39. Maki DG. Nosocomial bacteremia. An epidemiologic overview. Am J Med. 1981;70(3):719-32. DOI: 10.1016/0002-9343(81)90603-3

40. Kovacevich DS, Faubion WC, Bender JM, Schaberg DR, Wesley JR. Association of parenteral nutrition catheter sepsis with urinary tract infections. JPEN J Parenter Enteral Nutr. 1986;10(6):639-41. DOI: 10.1177/0148607186010006639

41. Yoshida T, Tsushima K, Tsuchiya A, Nishikawa N, Shirahata K, Kaneko K, Ito K, Kawakami H, Nakagawa S, Suzuki T, Kubo K, Ikeda S. Risk factors for hospital-acquired bacteremia. Intern Med. 2005;44(11):1157-62. DOI: 10.2169/internalmedicine.44.1157

42. Ehrenkranz NJ, Eckert DG, Phillips PM. Sporadic bacteremia complicating central venous catheter use in a community hospital: a model to predict frequency and aid in decision-making for initiation of investigation. Am J Infect Control. 1989;17(2):69-76. DOI: 10.1016/0196-6553(89)90020-5

43. Gastmeier P, Weist K, Rüden H. Catheter-associated primary bloodstream infections: epidemiology and preventive methods. Infection. 1999;27 Suppl(1):S1-6. DOI: 10.1007/BF02561609

44. Prävention Gefäßkatheter-assoziierter Infektionen: Empfehlungen der Kommission für Krankenhaushygiene und Infektionsprävention beim Robert Koch-Institut (RKI). Bundesgesundheitsbl – Gesundheitsforsch – Gesundheitsschutz. 2002;45(11):907-24.

45. Traoré O, Liotier J, Souweine B. Prospective study of arterial and central venous catheter colonization and of arterial- and central venous catheter-related bacteremia in intensive care units. Crit Care Med. 2005;33(6):1276-80. DOI: 10.1097/01.CCM.0000166350.90812.D4

46. Karthaus M, Doellmann T, Klimasch T, Krauter J, Heil G, Ganser A. Central venous catheter infections in patients with acute leukemia. Chemotherapy. 2002;48(3):154-7. DOI: 10.1159/000064922

47. Sandoe JA, Kumar B, Stoddart B, Milton R, Dave J, Nair UR, Wilcox MH. Effect of extended perioperative antibiotic prophylaxis on intravascular catheter colonization and infection in cardiothoracic surgery patients. J Antimicrob Chemother. 2003;52(5):877-9. DOI: 10.1093/jac/dkg442

48. Inglis GD, Davies MW. Prophylactic antibiotics to reduce morbidity and mortality in neonates with umbilical venous catheters. Cochrane Database Syst Rev. 2005;(4):CD005251.

49. Raymond J, Aujard Y. Nosocomial infections in pediatric patients: a European, multicenter prospective study. European Study Group. Infect Control Hosp Epidemiol. 2000;21(4):260-3. DOI: 10.1086/501755

50. Jarvis WR. Epidemiology of nosocomial infections in pediatric patients. Pediatr Infect Dis J. 1987;6(4):344-51.

51. Chien LY, Macnab Y, Aziz K, Andrews W, McMillan DD, Lee SK; Canadian Neonatal Network. Variations in central venous catheter-related infection risks among Canadian neonatal intensive care units. Pediatr Infect Dis J. 2002;21(6):505-11. DOI: 10.1097/00006454-200206000-00006

52. Urrea M, Pons M, Serra M, Latorre C, Palomeque A. Prospective incidence study of nosocomial infections in a pediatric intensive care unit. Pediatr Infect Dis J. 2003;22(6):490-4. DOI: 10.1097/01.inf.0000069758.00079.d3

53. Gastmeier P, Kampf G, Wischnewski N, Hauer T, Schulgen G, Schumacher M, Daschner F, Rüden H. Prevalence of nosocomial infections in representative German hospitals. J Hosp Infect. 1998;38(1):37-49. DOI: 10.1016/S0195-6701(98)90173-6

54. Hiesmayr. Estimates of nosocomial infections due to implantable biomaterials an Overview 2003. Personal communications. 2005.

55. Ryder M. Evidence-based practice in the management of vascular access devices for home parenteral nutrition therapy. JPEN J Parenter Enteral Nutr. 2006;30(1 Suppl):S82-93, S98-9.

56. Sherertz RJ, Ely EW, Westbrook DM, Gledhill KS, Streed SA, Kiger B, Flynn L, Hayes S, Strong S, Cruz J, Bowton DL, Hulgan T, Haponik EF. Education of physicians-in-training can decrease the risk for vascular catheter infection. Ann Intern Med. 2000;132(8):641-8.

57. Fridkin SK, Pear SM, Williamson TH, Galgiani JN, Jarvis WR. The role of understaffing in central venous catheter-associated bloodstream infections. Infect Control Hosp Epidemiol. 1996;17(3):150-8. DOI: 10.1086/647262

58. Pittet D, Wenzel RP. Nosocomial bloodstream infections. Secular trends in rates, mortality, and contribution to total hospital deaths. Arch Intern Med. 1995;155(11):1177-84. DOI: 10.1001/archinte.155.11.1177

59. Smith RL, Meixler SM, Simberkoff MS. Excess mortality in critically ill patients with nosocomial bloodstream infections. Chest. 1991;100(1):164-7. DOI: 10.1378/chest.100.1.164

60. Rello J, Ochagavia A, Sabanes E, Roque M, Mariscal D, Reynaga E, Valles J. Evaluation of outcome of intravenous catheter-related infections in critically ill patients. Am J Respir Crit Care Med. 200;162(3 Pt 1):1027-30.

61. Böswald M, Lugauer S, Regenfus A, Braun GG, Martus P, Geis C, Scharf J, Bechert T, Greil J, Guggenbichler JP. Reduced rates of catheter-associated infection by use of a new silver-impregnated central venous catheter. Infection. 1999;27 Suppl 1:S56-60. DOI: 10.1007/BF02561621

62. Soufir L, Timsit JF, Mahe C, Carlet J, Regnier B, Chevret S. Attributable morbidity and mortality of catheter-related septicemia in critically ill patients: a matched, risk-adjusted, cohort study. Infect Control Hosp Epidemiol. 1999;20(6):396-401. DOI: 10.1086/501639

63. Gilad J, Eskira S, Schlaeffer F, Vorobiov M, Marcovici A, Tovbin D, Zlotnik M, Borer A. Surveillance of chronic haemodialysis-associated infections in southern Israel. Clin Microbiol Infect. 2005;11(7):547-52. DOI: 10.1111/j.1469-0691.2005.01168.x

64. Tokars JI, Miller ER, Stein G. New national surveillance system for hemodialysis-associated infections: initial results. Am J Infect Control. 2002;30(5):288-95. DOI: 10.1067/mic.2002.120904

65. Stevenson KB, Adcox MJ, Mallea MC, Narasimhan N, Wagnild JP. Standardized surveillance of hemodialysis vascular access infections: 18-month experience at an outpatient, multifacility hemodialysis center. Infect Control Hosp Epidemiol. 2000;21(3):200-3. DOI: 10.1086/501744

66. Kim SH, Song KI, Chang JW, Kim SB, Sung SA, Jo SK, Cho WY, Kim HK. Prevention of uncuffed hemodialysis catheter-related bacteremia using an antibiotic lock technique: a prospective, randomized clinical trial. Kidney Int. 2006;69(1):161-4. DOI: 10.1038/sj.ki.5000012

67. Taylor G, Gravel D, Johnston L, Embil J, Holton D, Paton S; Canadian Nosocomial Infection Surveillance Program; Canadian Hospital Epidemiology Committee. Incidence of bloodstream infection in multicenter inception cohorts of hemodialysis patients. Am J Infect Control. 2004;32(3):155-60. DOI: 10.1016/j.ajic.2003.05.007

68. Souweine B, Traore O, Aublet-Cuvelier B, Badrikian L, Bret L, Sirot J, Gazuy N, Laveran H, Deteix P. Dialysis and central venous catheter infections in critically ill patients: results of a prospective study. Crit Care Med. 1999;27(11):2394-8. DOI: 10.1097/00003246-199911000-00012

69. Saeed Abdulrahman I, Al-Mueilo SH, Bokhary HA, Ladipo GO, Al-Rubaish A. A prospective study of hemodialysis access-related bacterial infections. J Infect Chemother. 2002;8(3):242-6. DOI: 10.1007/s10156-002-0184-8

70. Bonomo RA, Rice D, Whalen C, Linn D, Eckstein E, Shlaes DM. Risk factors associated with permanent access-site infections in chronic hemodialysis patients. Infect Control Hosp Epidemiol. 1997;18(11):757-61. DOI: 10.1086/647530

71. Klevens RM, Tokars JI, Andrus M. Electronic reporting of infections associated with hemodialysis. Nephrol News Issues. 2005;19(7):37-8, 43.

72. Lerner GR, Warady BA, Sullivan EK, Alexander SR. Chronic dialysis in children and adolescents. The 1996 annual report of the North American Pediatric Renal Transplant Cooperative Study. Pediatr Nephrol. 1999;13(5):404-17. DOI: 10.1007/s004670050631

73. Vercaigne LM, Zelenitsky SA, Findlay I, Bernstein K, Penner SB. An in vitro evaluation of the antibiotic/heparin lock to sterilize central venous haemodialysis catheters. J Antimicrob Chemother. 2002;49(4):693-6. DOI: 10.1093/jac/49.4.693

74. Cornely OA, Bethe U, Pauls R, Waldschmidt DTh. Phlebitisinzidenz peripherer Teflon Venenverweilkatheter. HygMed. 2002;27(10):400-404.

75. Soifer NE, Borzak S, Edlin BR, Weinstein RA. Prevention of peripheral venous catheter complications with an intravenous therapy team: a randomized controlled trial. Arch Intern Med. 1998;158(5):473-7. DOI: 10.1001/archinte.158.5.473

76. Ena J, Cercenado E, Martinez D, Bouza E. Cross-sectional epidemiology of phlebitis and catheter-related infections. Infect Control Hosp Epidemiol. 1992;13(1):15-20. DOI: 10.1086/646418

77. Maki DG, Ringer M. Risk factors for infusion-related phlebitis with small peripheral venous catheters. A randomized controlled trial. Ann Intern Med. 1991;114(10):845-54.

78. Shimandle RB, Johnson D, Baker M, Stotland N, Karrison T, Arnow PM. Safety of peripheral intravenous catheters in children. Infect Control Hosp Epidemiol. 1999;20(11):736-40. DOI: 10.1086/501574

79. Stegmayr B. Advantages and disadvantages of surgical placement of PD catheters with regard to other methods. Int J Artif Organs. 2006;29(1):95-100.

80. Piraino B, Bailie GR, Bernardini J, Boeschoten E, Gupta A, Holmes C, Kuijper EJ, Li PK, Lye WC, Mujais S, Paterson DL, Fontan MP, Ramos A, Schaefer F, Uttley L; ISPD Ad Hoc Advisory Committee. Peritoneal dialysis-related infections recommendations: 2005 update. Perit Dial Int. 2005;25(2):107-31.

81. Borazan A, Comert M, Ucan BH, Comert FB, Sert M, Sekitmez N, Cesur A. The comparison in terms of early complications of a new technique and percutaneous method for the placement of CAPD catheters. Ren Fail. 2006;28(1):37-42. DOI: 10.1080/08860220500461237

82. Boehm M, Vécsei A, Aufricht C, Mueller T, Csaicsich D, Arbeiter K. Risk factors for peritonitis in pediatric peritoneal dialysis: a single-center study. Pediatr Nephrol. 2005;20(10):1478-83. DOI: 10.1007/s00467-005-1953-2

83. Troidle L, Gorban-Brennan N, Kliger A, Finkelstein FO. Continuous peritoneal dialysis-associated peritonitis: a review and current concepts. Semin Dial. 2003;16(6):428-37. DOI: 10.1046/j.1525-139X.2003.16095.x

84. Bernardini J, Bender F, Florio T, Sloand J, Palmmontalbano L, Fried L, Piraino B. Randomized, double-blind trial of antibiotic exit site cream for prevention of exit site infection in peritoneal dialysis patients. J Am Soc Nephrol. 2005;16(2):539-45. DOI: 10.1681/ASN.2004090773

85. Zelenitsky S, Barns L, Findlay I, Alfa M, Ariano R, Fine A, Harding G. Analysis of microbiological trends in peritoneal dialysis-related peritonitis from 1991 to 1998. Am J Kidney Dis. 2000;36(5):1009-13. DOI: 10.1053/ajkd.2000.19103

86. Chow KM, Szeto CC, Leung CB, Kwan BC, Law MC, Li PK. A risk analysis of continuous ambulatory peritoneal dialysis-related peritonitis. Perit Dial Int. 2005;25(4):374-9.

87. Levy M, Balfe JW, Geary D, Fryer-Keene SP. Factors predisposing and contributing to peritonitis during chronic peritoneal dialysis in children: a ten-year experience. Perit Dial Int. 1990;10(4):263-9.

88. Decker MD, Edwards KM. Central venous catheter infections. Pediatr Clin North Am. 1988;35(3):579-612.

89. Armstrong CW, Mayhall CG, Miller KB, Newsome HH Jr, Sugerman HJ, Dalton HP, Hall GO, Hunsberger S. Clinical predictors of infection of central venous catheters used for total parenteral nutrition. Infect Control Hosp Epidemiol. 1990;11(2):71-8. DOI: 10.1086/646125

90. Stamou SC, Maltezou HC, Pourtsidis A, Psaltopoulou T, Skondras C, Aivazoglou T. Hickman-Broviac catheter-related infections in children with malignancies. Mt Sinai J Med. 1999;66(5-6):320-6.

91. Adler A, Yaniv I, Steinberg R, Solter E, Samra Z, Stein J, Levy I. Infectious complications of implantable ports and Hickman catheters in paediatric haematology-oncology patients. J Hosp Infect. 2006;62(3):358-65. DOI: 10.1016/j.jhin.2005.08.019

92. Simon A. Jahrestagung Inf. Päd. Onkologie, Düsseldorf, Nov. 2003

93. Rosenthal VD, Maki DG. Prospective study of the impact of open and closed infusion systems on rates of central venous catheter-associated bacteremia. Am J Infect Control. 2004;32(3):135-41. DOI: 10.1016/j.ajic.2003.12.002

94. Fratino G, Molinari AC, Parodi S, Longo S, Saracco P, Castagnola E, Haupt R. Central venous catheter-related complications in children with oncological/hematological diseases: an observational study of 418 devices. Ann Oncol. 2005;16(4):648-54. DOI: 10.1093/annonc/mdi111

95. Biffi R, Pozzi S, Agazzi A, Pace U, Floridi A, Cenciarelli S, Peveri V, Cocquio A, Andreoni B, Martinelli G. Use of totally implantable central venous access ports for high-dose chemotherapy and peripheral blood stem cell transplantation: results of a monocentre series of 376 patients. Ann Oncol. 2004;15(2):296-300. DOI: 10.1093/annonc/mdh049

96. Guggenbichler M. Entwicklung eines antimikrobiellen PORT Katheters aus Keramik mit einer verbesserten Kammergeometrie. Thesis for PhD Techn. Eng.: Univ Bayreuth; June 2004.

97. Salzman MB, Rubin LG. Intravenous catheter-related infections. Adv Pediatr Infect Dis. 1995;10:337-68.

98. Wildhaber B, Kistler W, Caflisch U. Erfahrungen mit dem Port-a-Cath System bei Kindern [Experiences with the Port-A-Cath system in children]. Schweiz Med Wochenschr. 2000;130(20):732-8.

99. Mehta RM, Niederman MS. Nosocomial pneumonia in the intensive care unit: controversies and dilemmas. J Intensive Care Med. 2003;18(4):175-88. DOI: 10.1177/0885066603254249

100. Diaz E, Rodríguez AH, Rello J. Ventilator-associated pneumonia: issues related to the artificial airway. Respir Care. 2005;50(7):900-6.

101. Cunnion KM, Weber DJ, Broadhead WE, Hanson LC, Pieper CF, Rutala WA. Risk factors for nosocomial pneumonia: comparing adult critical-care populations. Am J Respir Crit Care Med. 1996;153(1):158-62.

102. Fagon JY, Chastre J, Vuagnat A, Trouillet JL, Novara A, Gibert C. Nosocomial pneumonia and mortality among patients in intensive care units. JAMA. 1996;275(11):866-9. DOI: 10.1001/jama.275.11.866

103. Bonten MJ, Kollef MH, Hall JB. Risk factors for ventilator-associated pneumonia: from epidemiology to patient management. Clin Infect Dis. 2004;38(8):1141-9. DOI: 10.1086/383039

104. Rello J, Lorente C, Diaz E, Bodi M, Boque C, Sandiumenge A, Santamaria JM. Incidence, etiology, and outcome of nosocomial pneumonia in ICU patients requiring percutaneous tracheotomy for mechanical ventilation. Chest. 2003;124(6):2239-43. DOI: 10.1378/chest.124.6.2239

105. Safdar N, Crnich CJ, Maki DG. The pathogenesis of ventilator-associated pneumonia: its relevance to developing effective strategies for prevention. Respir Care. 2005;50(6):725-39.

106. Cook DJ, Kollef MH. Risk factors for ICU-acquired pneumonia. JAMA. 1998;279(20):1605-6. DOI: 10.1001/jama.279.20.1605

107. Bonten MJ, Gaillard CA, de Leeuw PW, Stobberingh EE. Role of colonization of the upper intestinal tract in the pathogenesis of ventilator-associated pneumonia. Clin Infect Dis. 1997;24(3):309-19. DOI: 10.1093/clinids/24.3.309

108. Hurley JC. Prophylaxis with enteral antibiotics in ventilated patients: selective decontamination or selective cross-infection? Antimicrob Agents Chemother. 1995;39(4):941-7.

109. Hurley JC. Inapparent outbreaks of ventilator-associated pneumonia: an ecologic analysis of prevention and cohort studies. Infect Control Hosp Epidemiol. 2005;26(4):374-90. DOI: 10.1086/502555

110. Adair CG, Gorman SP, Feron BM, Byers LM, Jones DS, Goldsmith CE, Moore JE, Kerr JR, Curran MD, Hogg G, Webb CH, McCarthy GJ, Milligan KR. Implications of endotracheal tube biofilm for ventilator-associated pneumonia. Intensive Care Med. 1999;25(10):1072-6. DOI: 10.1007/s001340051014

111. Salathe M, Wanner A. Nonspecific host defenses: Mucociliary clearance and cough. In: Niederman MS, Sarosi GA, Glassroth J, eds. Respiratory Infections: A Scientific Basis for Management. Philadelphia: WB Saunders; 1994. P. 17-32.

112. Zeiher BG, Hornick DB. Pathogenesis of respiratory infections and host defenses. Curr Opin Pulm Med. 1996;2(3):166-73. DOI: 10.1097/00063198-199605000-00002

113. Markowicz P, Wolff M, Djedaïni K, Cohen Y, Chastre J, Delclaux C, Merrer J, Herman B, Veber B, Fontaine A, Dreyfuss D. Multicenter prospective study of ventilator-associated pneumonia during acute respiratory distress syndrome. Incidence, prognosis, and risk factors. ARDS Study Group. Am J Respir Crit Care Med. 2000;161(6):1942-8.

114. Alcón A, Fàbregas N, Torres A. Hospital-acquired pneumonia: etiologic considerations. Infect Dis Clin North Am. 2003;17(4):679-95. DOI: 10.1016/S0891-5520(03)00074-6

115. Nseir S, Di Pompeo C, Soubrier S, Cavestri B, Jozefowicz E, Saulnier F, Durocher A. Impact of ventilator-associated pneumonia on outcome in patients with COPD. Chest. 2005;128(3):1650-6. DOI: 10.1378/chest.128.3.1650

116. Ensminger SA, Wright RS, Baddour LM, Afessa B. Suspected ventilator-associated pneumonia in cardiac patients admitted to the coronary care unit. Mayo Clin Proc. 2006;81(1):32-5. DOI: 10.4065/81.1.32

117. Anzueto A, Frutos-Vivar F, Esteban A, Alía I, Brochard L, Stewart T, Benito S, Tobin MJ, Elizalde J, Palizas F, David CM, Pimentel J, González M, Soto L, D'Empaire G, Pelosi P. Incidence, risk factors and outcome of barotrauma in mechanically ventilated patients. Intensive Care Med. 2004;30(4):612-9. DOI: 10.1007/s00134-004-2187-7

118. Ibrahim EH, Mehringer L, Prentice D, Sherman G, Schaiff R, Fraser V, Kollef MH. Early versus late enteral feeding of mechanically ventilated patients: results of a clinical trial. JPEN J Parenter Enteral Nutr. 2002;26(3):174-81. DOI: 10.1177/0148607102026003174

119. Georges H, Leroy O, Guery B, Alfandari S, Beaucaire G. Predisposing factors for nosocomial pneumonia in patients receiving mechanical ventilation and requiring tracheotomy. Chest. 2000;118(3):767-74. DOI: 10.1378/chest.118.3.767

120. Andrews P, Azoulay E, Antonelli M, Brochard L, Brun-Buisson C, Dobb G, Fagon JY, Gerlach H, Groeneveld J, Mancebo J, Metnitz P, Nava S, Pugin J, Pinsky M, Radermacher P, Richard C, Tasker R. Year in review in intensive care medicine, 2005. II. Infection and sepsis, ventilator-associated pneumonia, ethics, haematology and haemostasis, ICU organisation and scoring, brain injury. Intensive Care Med. 2006;32(3):380-90. DOI: 10.1007/s00134-005-0060-y

121. Rouby JJ, Laurent P, Gosnach M, Cambau E, Lamas G, Zouaoui A, Leguillou JL, Bodin L, Khac TD, Marsault C, et al. Risk factors and clinical relevance of nosocomial maxillary sinusitis in the critically ill. Am J Respir Crit Care Med. 1994;150(3):776-83.

122. Holzapfel L, Chastang C, Demingeon G, Bohe J, Piralla B, Coupry A. A randomized study assessing the systematic search for maxillary sinusitis in nasotracheally mechanically ventilated patients. Influence of nosocomial maxillary sinusitis on the occurrence of ventilator-associated pneumonia. Am J Respir Crit Care Med. 1999;159(3):695-701.

123. Smulders K, van der Hoeven H, Weers-Pothoff I, Vandenbroucke-Grauls C. A randomized clinical trial of intermittent subglottic secretion drainage in patients receiving mechanical ventilation. Chest. 2002;121(3):858-62. DOI: 10.1378/chest.121.3.858

124. Lacherade JC, Auburtin M, Cerf C, Van de Louw A, Soufir L, Rebufat Y, Rezaiguia S, Ricard JD, Lellouche F, Brun-Buisson C, Brochard L. Impact of humidification systems on ventilator-associated pneumonia: a randomized multicenter trial. Am J Respir Crit Care Med. 2005;172(10):1276-82. DOI: 10.1164/rccm.200408-1028OC

125. Bonten MJ. Prevention of hospital-acquired pneumonia: European perspective. Infect Dis Clin North Am. 2003;17(4):773-84. DOI: 10.1016/S0891-5520(03)00068-0

126. Mattner F, Gastmeier P; Centers of Disease Control and Prevention; Healthcare Infection Control Practices Advisory Committee. Empfehlungen zur Pravention nosokomialer Pneumonien [Guidelines for preventing health-care-associated pneumonia]. Anasthesiol Intensivmed Notfallmed Schmerzther. 2005;40(2):79-84. DOI: 10.1055/s-2004-825929

127. Bagshaw SM, Laupland KB. Epidemiology of intensive care unit-acquired urinary tract infections. Curr Opin Infect Dis. 2006;19(1):67-71. DOI: 10.1097/01.qco.0000200292.37909.e0

128. Kontiokari T, Nuutinen M, Uhari M. Dietary factors affecting susceptibility to urinary tract infection. Pediatr Nephrol. 2004;19(4):378-83. DOI: 10.1007/s00467-003-1410-z

129. Mühlemann K, Franzini C, Aebi C, Berger C, Nadal D, Stähelin J, Gnehm H, Posfay-Barbe K, Gervaix A, Sax H, Heininger U, Bonhoeffer J, Eich G, Kind C, Petignat C, Scalfaro P. Prevalence of nosocomial infections in Swiss children's hospitals. Infect Control Hosp Epidemiol. 2004;25(9):765-71.

130. Laupland KB, Zygun DA, Davies HD, Church DL, Louie TJ, Doig CJ. Incidence and risk factors for acquiring nosocomial urinary tract infection in the critically ill. J Crit Care. 2002;17(1):50-7. DOI: 10.1053/jcrc.2002.33029

131. Liu JW, Hsu YM, Huang YF. Independent prognostic factors for fatality in patients with urinary tract infection caused by Serratia marcescens. Infect Control Hosp Epidemiol. 2004;25(1):80-2. DOI: 10.1086/502297

132. Warren JW. Catheter-associated urinary tract infections. Infect Dis Clin North Am. 1997;11(3):609-22. DOI: 10.1016/S0891-5520(05)70376-7

133. Brühl P, Widmann T, Sökeland J, Reybrouck G. Nosocomial urinary tract infections: etiology and prevention. Urol Int. 1986;41(6):437-43. DOI: 10.1159/000281252

134. Margolin DJ, Gonzalez RP. Retrospective analysis of traumatic bladder injury: does suprapubic catheterization alter outcome of healing? Am Surg. 2004;70(12):1057-60.

135. Pong A, Bradley JS. Clinical challenges of nosocomial infections caused by antibiotic-resistant pathogens in pediatrics. Semin Pediatr Infect Dis. 2004;15(1):21-9. DOI: 10.1053/j.spid.2004.01.005

136. Maki DG, Tambyah PA. Engineering out the risk for infection with urinary catheters. Emerg Infect Dis. 2001;7(2):342-7. DOI: 10.3201/eid0702.010240

137. Popp W, Müller O, Schoch B, Hansen D, Müller D. Stolke D. Infektionsraten bei externen Ventrikeldrainagen. Hyg Med. 2000;(Suppl 1):43.

138. Pfisterer W, Mühlbauer M, Czech T, Reinprecht A. Early diagnosis of external ventricular drainage infection: results of a prospective study. J Neurol Neurosurg Psychiatry. 2003;74(7):929-32. DOI: 10.1136/jnnp.74.7.929

139. Wang KC, Lee HJ, Sung JN, Cho BK. Cerebrospinal fluid shunt infection in children: efficiency of management protocol, rate of persistent shunt colonization, and significance of 'off-antibiotics' trial. Childs Nerv Syst. 1999;15(1):38-43. DOI: 10.1007/s003810050324

140. Blount JP, Haynes SJ. Infections in cerebrospinal shunts. In: Yourmas JR, eds. Neurological surgery. 4th ed. Philadelphia: Saunders; 1996. P. 943-966.

141. Müller O, Schoch B, Hansen D, Popp W, Stolke D. Harmful use of prophylactic antibiotics in the treatment with external ventricular drainages to prevent infections of the cerebrospinal fluid. In: 56. Jahrestagung der Deutschen Gesellschaft für Neurochirurgie e.V. (DGNC), 3èmes journées françaises de Neurochirurgie (SFNC); 07.–11.05.2005; Strasbourg, FR. Available from: http://www.egms.de/static/de/meetings/dgnc2005/05dgnc0176.shtml

142. Steckelberg JM, Osmon DR. Prosthetic Joint Infection. In: Bisno AL, Waldvogel FA, eds. 3rd ed. Washington, DC: Am Soc Microbiol; 2000. P. 173-209.

143. Widmer AF. New developments in diagnosis and treatment of infection in orthopedic implants. Clin Infect Dis. 2001;33(Suppl 2):S94-106. DOI: 10.1086/321863

144. Zimmerli W, Trampuz A, Ochsner PE. Prosthetic-joint infections. N Engl J Med. 2004;351(16):1645-54. DOI: 10.1056/NEJMra040181

145. Segawa H, Tsukayama DT, Kyle RF, Becker DA, Gustilo RB. Infection after total knee arthroplasty. A retrospective study of the treatment of eighty-one infections. J Bone Joint Surg Am. 1999;81(10):1434-45.

146. Giulieri SG, Graber P, Ochsner PE, Zimmerli W. Management of infection associated with total hip arthroplasty according to a treatment algorithm. Infection. 2004;32(4):222-8. DOI: 10.1007/s15010-004-4020-1

147. Murdoch DR, Roberts SA, Fowler Jr VG Jr, Shah MA, Taylor SL, Morris AJ, Corey GR. Infection of orthopedic prostheses after Staphylococcus aureus bacteremia. Clin Infect Dis. 2001;32(4):647-9. DOI: 10.1086/318704

148. Trampuz A, Steckelberg JM, Osmon DR, Cockervill FR, Hanssen AD, Patel R. Advances in the laboratory diagnosis of prosthetic joint infection. Rev Med Microbiol. 2003;14:1-14.

149. Zimmerli W, Frei R, Widmer AF, Rajacic Z. Microbiological tests to predict treatment outcome in experimental device-related infections due to Staphylococcus aureus. J Antimicrob Chemother. 1994;33(5):959-67. DOI: 10.1093/jac/33.5.959

150. Spangehl MJ, Masri BA, O'Connell JX, Duncan CP. Prospective analysis of preoperative and intraoperative investigations for the diagnosis of infection at the sites of two hundred and two revision total hip arthroplasties. J Bone Joint Surg Am. 1999;81(5):672-83.

151. Ure KJ, Amstutz HC, Nasser S, Schmalzried TP. Direct-exchange arthroplasty for the treatment of infection after total hip replacement. An average ten-year follow-up. J Bone Joint Surg Am. 1998;80(7):961-8.

152. Berbari EF, Osmon DR, Duffy MC, Harmssen RN, Mandrekar JN, Hanssen AD, Steckelberg JM. Outcome of prosthetic joint infection in patients with rheumatoid arthritis: the impact of medical and surgical therapy in 200 episodes. Clin Infect Dis. 2006;42(2):216-23. DOI: 10.1086/498507

153. Powell DL, Whitener CJ, Dye CE, Ballard JO, Shaffer ML, Eyster ME. Knee and hip arthroplasty infection rates in persons with haemophilia: a 27 year single center experience during the HIV epidemic. Haemophilia. 2005 May;11(3):233-9. DOI: 10.1111/j.1365-2516.2005.01081.x

154. Brandt CM, Sistrunk WW, Duffy MC, Hanssen AD, Steckelberg JM, Ilstrup DM, Osmon DR. Staphylococcus aureus prosthetic joint infection treated with debridement and prosthesis retention. Clin Infect Dis. 1997;24(5):914-9. DOI: 10.1093/clinids/24.5.914

155. Nolla JM, Gómez-Vaquero C, Corbella X, Ordóñez S, García-Gómez C, Pérez A, Cabo J, Valverde J, Ariza J. Group B streptococcus (Streptococcus agalactiae) pyogenic arthritis in nonpregnant adults. Medicine (Baltimore). 2003;82(2):119-28. DOI: 10.1097/00005792-200303000-00006

156. Salemi C, Anderson D, Flores D. American Society of Anesthesiology scoring discrepancies affecting the National Nosocomial Infection Surveillance System: surgical-site-infection risk index rates. Infect Control Hosp Epidemiol. 1997;18(4):246-7. DOI: 10.1086/647603

157. Trampuz A, Zimmerli W. New strategies for the treatment of infections associated with prosthetic joints. Curr Opin Investig Drugs. 2005;6(2):185-90.

158. Camus C, Leport C, Raffi F, Michelet C, Cartier F, Vilde JL. Sustained bacteremia in 26 patients with a permanent endocardial pacemaker: assessment of wire removal. Clin Infect Dis. 1993;17(1):46-55. DOI: 10.1093/clinids/17.1.46

159. Bluhm G. Pacemaker infections. A clinical study with special reference to prophylactic use of some isoxazolyl penicillins. Acta Med Scand Suppl. 1985;699:1-62.

160. Mueller X, Sadeghi H, Kappenberger L. Complications after single versus dual chamber pacemaker implantation. Pacing Clin Electrophysiol. 1990;13(6):711-4. DOI: 10.1111/j.1540-8159.1990.tb02095.x

161. Bailey SM, Wilkoff BL. Complications of pacemakers and defibrillators in the elderly. Am J Geriatr Cardiol. 2006;15(2):102-7. DOI: 10.1111/j.1076-7460.2006.04815.x

162. Kinoshita O, Amano J, Takano T, Kitahara H, Itou K, Uchikawa S, Yazaki Y, Imamura H, Hongo M, Kubo K. Bacteremia caused by late-infected pacemaker lead – a case report. Angiology. 2004;55(6):697-9. DOI: 10.1177/000331970405501612

163. Myers MR, Parsonnet V, Bernstein AD. Extraction of implanted transvenous pacing leads: a review of a persistent clinical problem. Am Heart J. 1991;121(3 Pt 1):881-8. DOI: 10.1016/0002-8703(91)90203-T

164. Rettig G, Doenecke P, Sen S, Volkmer I, Bette L. Complications with retained transvenous pacemaker electrodes. Am Heart J. 1979;98(5):587-94. DOI: 10.1016/0002-8703(79)90284-9

165. Parry G, Goudevenos J, Jameson S, Adams PC, Gold RG. Complications associated with retained pacemaker leads. Pacing Clin Electrophysiol. 1991;14(8):1251-7. DOI: 10.1111/j.1540-8159.1991.tb02864.x

166. Rundström H, Kennergren C, Andersson R, Alestig K, Hogevik H. Pacemaker endocarditis during 18 years in Göteborg. Scand J Infect Dis. 2004;36(9):674-9.

167. Karchmer AW, Longworth DL. Infections of intracardiac devices. Cardiol Clin. 2003;21(2):253-71. DOI: 10.1016/S0733-8651(03)00032-8

168. Belikov S, Marijic J, Laks H, Staudacher M, Boyle N, Shivkumar K, Odim J. Sepsis from insidious pacemaker infection and unsuspected tricuspid valve endocarditis: the importance of transesophageal echocardiography in guiding explantation strategy. J Cardiothorac Vasc Anesth. 2005;19(4):505-7. DOI: 10.1053/j.jvca.2005.05.009

169. Mansencal N, Lavergne T, Bordachar P, Abergel E, Le Heuzey JY, Hidden F, Guize L. Chronic cor pulmonale: a rare complication of undiagnosed pacemaker lead endocarditis. Int J Cardiol. 2004;96(1):119-20. DOI: 10.1016/j.ijcard.2003.04.054

170. Eng MM, Power RE, Hickey DP, Little DM. Vascular complications of allograft nephrectomy. Eur J Vasc Endovasc Surg. 2006;32(2):212-6. DOI: 10.1016/j.ejvs.2006.01.008

171. Ali AT, Bell C, Modrall JG, Valentine RJ, Clagett GP. Graft-associated hemorrhage from femoropopliteal vein grafts. J Vasc Surg. 2005;42(4):667-72. DOI: 10.1016/j.jvs.2005.06.002

172. Killewich LA. Improving functional status and quality of life in elderly patients with peripheral arterial disease. J Am Coll Surg. 2006;202(2):345-55. DOI: 10.1016/j.jamcollsurg.2005.09.026

173. Mertens RA, O'Hara PJ, Hertzer NR, Krajewski LP, Beven EG. Surgical management of infrainguinal arterial prosthetic graft infections: review of a thirty-five-year experience. J Vasc Surg. 1995;21(5):782-90. DOI: 10.1016/S0741-5214(05)80009-6

174. Castier Y, Francis F, Cerceau P, Besnard M, Albertin J, Fouilhe L, Cerceau O, Albaladejo P, Lesèche G. Cryopreserved arterial allograft reconstruction for peripheral graft infection. J Vasc Surg. 2005;41(1):30-7. DOI: 10.1016/j.jvs.2004.09.025

175. Pirrelli S, Arici V, Bozzani A, Odero A. Aortic graft infections: treatment with arterial allograft. Transplant Proc. 2005;37(6):2694-6. DOI: 10.1016/j.transproceed.2005.06.098

176. Pounds LL, Montes-Walters M, Mayhall CG, Falk PS, Sanderson E, Hunter GC, Killewich LA. A changing pattern of infection after major vascular reconstructions. Vasc Endovascular Surg. 2005;39(6):511-7. DOI: 10.1177/153857440503900608

177. Georgiadis GS, Lazarides MK, Polychronidis A, Simopoulos C. Surgical treatment of femoral artery infected false aneurysms in drug abusers. ANZ J Surg. 2005;75(11):1005-10. DOI: 10.1111/j.1445-2197.2005.03578.x

178. Toumpoulis IK, Anagnostopoulos CE, Balaram SK, Rokkas CK, Swistel DG, Ashton RC Jr, DeRose JJ Jr. Assessment of independent predictors for long-term mortality between women and men after coronary artery bypass grafting: are women different from men? J Thorac Cardiovasc Surg. 2006;131(2):343-51. DOI: 10.1016/j.jtcvs.2005.08.056

179. Ali AT, Bell C, Modrall JG, Valentine RJ, Clagett GP. Graft-associated hemorrhage from femoropopliteal vein grafts. J Vasc Surg. 2005;42(4):667-72. DOI: 10.1016/j.jvs.2005.06.002

180. Earnshaw JJ, Slack RC, Hopkinson BR, Makin GS. Risk factors in vascular surgical sepsis. Ann R Coll Surg Engl. 1988;70(3):139-43.

181. Bosiers M, Deloose K, Verbist J, Schroë H, Lauwers G, Lansink W, Peeters P. Heparin-bonded expanded polytetrafluoroethylene vascular graft for femoropopliteal and femorocrural bypass grafting: 1-year results. J Vasc Surg. 2006;43(2):313-8. DOI: 10.1016/j.jvs.2005.10.037

182. Schmacht D, Armstrong P, Johnson B, Pierre K, Back M, Honeyman A, Cuthbertson D, Bandyk D. Graft infectivity of rifampin and silver-bonded polyester grafts to MRSA contamination. Vasc Endovascular Surg. 2005;39(5):411-20. DOI: 10.1177/153857440503900505

183. Cook RJ, Ashton RW, Aughenbaugh GL, Ryu JH. Septic pulmonary embolism: presenting features and clinical course of 14 patients. Chest. 2005;128(1):162-6. DOI: 10.1378/chest.128.1.162

184. Kaye KS, Engemann JJ, Fulmer EM, Clark CC, Noga EM, Sexton DJ. Favorable impact of an infection control network on nosocomial infection rates in community hospitals. Infect Control Hosp Epidemiol. 2006;27(3):228-32. DOI: 10.1086/500371

185. Renaud B, Brun-Buisson C; ICU-Bacteremia Study Group. Outcomes of primary and catheter-related bacteremia. A cohort and case-control study in critically ill patients. Am J Respir Crit Care Med. 2001;163(7):1584-90.

186. Safdar N, Maki DG. Inflammation at the insertion site is not predictive of catheter-related bloodstream infection with short-term, noncuffed central venous catheters. Crit Care Med. 2002;30(12):2632-5. DOI: 10.1097/00003246-200212000-00003

187. Douard MC, Arlet G, Leverger G, Paulien R, Waintrop C, Clementi E, Eurin B, Schaison G. Quantitative blood cultures for diagnosis and management of catheter-related sepsis in pediatric hematology and oncology patients. Intensive Care Med. 1991;17(1):30-5. DOI: 10.1007/BF01708406

Erratum

In the section "Central venous catheters: intermediate (Sheldon)" the indication "(11.97/10,000 days, 28.81/10,000 haemodialysis procedures)" has been changed in "(11.97/1,000 days, 28.81/1,000 haemodialysis procedures)".
The text has been linguistically improved.

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