Fighting Hospital infections with Engineering 4.0

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Abstract. In the repeated interventions carried out by the authors in the healthcare sector [1], [2], [3], [4] (hospitals, outpatient clinics and clinics), including assistance facilities (residences for the elderly and outpatient medical offices) the problem of so-called hospital or nosocomial infections has always been reported to the team by the medical and nursing staff. Starting from an age-old experience of sanitization of confined environments, achieved by the authors by using a 4.0 machine, for the production of gaseous ozone and UVC rays [8], it was required to the team to extend the benefits achieved to the healthcare sector. This goal was possible by generating a dedicated approach, for an effective action to combat this serious problem of global significance. The machine mentioned was conceptualized, designed and developed by the authors by specific Engineering 4.0 methodologies, meaning with this term the use of all Engineering technologies, techniques, software, tools, and devices characterizing the fourth industrial revolution.

Keywords: Hospital infections, sanitization 4.0, ozone, UVC.

1 Identification of risk phases

In the normal management of an operating block, both patients and operators face continuous risks for their safety. It is known, in fact, that the surgical patients are, not infrequently, subject to aggression by viruses and bacteria, to heal which it is necessary to intervene with difficult explicit treatments, due to the resistance developed by pathogens to drugs, in operating blocks. The direct consequence is the infections for the patients and the related costs for the institution, which must provide appropriate treatment. In addition to this, there is the possible presence of insects, molds and even rodents. To combat these entities is not trivial due to the impossibility of intervention with common insecticides and rat poisoning, in a sterile environment. Another problem frequently encountered, especially in periods of overload of interventions, is the fact that a surgical instrument escapes the control of the operators being left into the patient's body, with the need to provide for its urgent removal. In this case it is easy to imagine the impact on the patient and for the institution. Then, with regard to the staff responsible of washing the surgical irons arriving "dirty" from the operating rooms requiring a pre-treatment upstream to the sterilization cycle, it must be considered the risk of cuts or punctures, with easily imaginable consequences.

2 Hospital infections

From the literature of the sector, it is highlighted what is reported in the following regarding this important problem [10]. Hospital or nosocomial infections are infectious diseases acquired in hospitals or in healthcare settings (like nursing homes, long-term hospitalizations, long-term clinics, residences for the elderly, etc.) that affect between 5% and 10% of patients, causing 80,000 deaths a year in the US alone. To be defined as hospital infections, the patient must have been hospitalized for a cause other than the infection in question and must not have signs of an infectious disease being incubated at the time of admission. It is therefore necessary to be sure that it was contracted in the facility. Such infections normally occur 48 hours after hospitalization, or up to 3 days after dismission, or up to 30 days after an operation. The timing varies according to the type of infection and the viral load affecting the patient. The most frequent are septicemia due to venous access, where a needle has been inserted (about 50% of cases of infection), pneumonia and infections of the respiratory tract (21%, constantly increasing), urinary tract (10.5%). According to more recent studies, today they amount to 30/40% of the total hospital infections, attacking the skin and soft tissues (9.8%), the ear, nose, throat and eye (3%), the osteoarticular system (2%), the nervous system (1%), the cardiovascular system (0.3%), the surgical and decubitus wounds (8% of hospitalized, and between 15 and 25% of hospitalized wards for long hospitalization). The interventions, on the other hand, can cause a wide series of infections, ranging from the superficial ones of the skin to the very deep ones of tissues, organs and implants. Colon surgery in Italy is a highly risky procedure, with an infection rate of almost 9% of interventions. A serious problem is that 70% of the bacteria involved are resistant to common antibiotics as they are used to enduring very strong pharmacological pressure. The simple washing of hands before any operation leads to the prevention of 25% of infections, therefore a system of sterilization and sanitization of the environments and objects touched by the operators leads to a strong reduction in the chances of infection. Pathogens are various and the predominant ones in Italy are staphylococcus aureus (36% of cases in the south, 34% in the north and 25% in the center), Pseudomonas aeruginosa (32% of cases in the center, 30% in the south and 19% in the north), escherichia coli (25% of cases in the north, 18% in the center, 13% in the south), staphylococcus epidermidis (12% of cases in the center, 10% in both north and south), enterococcus faecalis and enterococcus fecium (7% of cases in the center, 6% in the north, 5% in the south), klebsiella pneumoniae (6% of cases both in the south and in the center and in the north).

3 Sanitization 4.0

With regard to the problem of sanitization, which is a crucial in the management of operating blocks, important improvements can be brought to traditional methods, using engineering 4.0 and its technologies for production and control of UVC rays and gaseous ozone. A relevant aspect in an operating block 4.0 is guaranteeing a constant sanitization, by means of UVC rays, of the “filter area”, which is the room located in front of any operating room. Also, to protect the operators, who not infrequently get injured by treating dirty surgical instruments (major concern), it was developed a "hand free" pre-sanitization method of the surgical equipment trays. It is performed by a machine of under pressure pre-washing and UVC treatment, by appropriate 4.0 technology, conceptualized and developed by the authors. The proposed process of environmental sanitization consists in 2 steps: a) quick treatment, the operating block is treated, with UVC rays, controlled in wavelength and frequency, for only a few minutes between one patient and the next, providing major guarantees from the current sanitization; b) deep treatment, at the end of the shift, a radical treatment is provided with gaseous ozone, produced centrally by a special 4.0 plant, thus guaranteeing deep sanitization against viruses, bacteria, insects, fungi, spores and so on (because capable of penetrating in fabrics and mattresses, as scientifically recognized by the literature of sector on a planetary level). This sanitization performance is achieved with relevant advantages like quick treatment, at negligible costs, and with a fast resume of the room to re populate. In fact, both the proposed treatments do not leave any residue in the environment. Treatments are conducted in the absence of personnel, not generating risks or requiring subsequent cleaning. For an in-depth analysis of the subject in question, please refer to the full text of the paper presented by Marco Mosca at the IAENG-WCE 2021 (International Association of Engineers, Word Congress on Engineering), publication awarded as best paper for the bioengineering section.
In short, the method proposed for the sanitization of environments consist 2 phases, by means of the machine designed and developed by the authors, described in paper [8]:

- irradiation with UVC rays (at a fixed distance and for tabulated timing);
- exposure to a certain concentration of ozone (produced from the air, at a negligible cost) for tabulated timing, according to the agent to be sanitized. The machine is capable to reproduce the Chapman-cycle in the environment, as it occurs in the Ozonosphere. As the wavelength of UVC rays varies, the oxygen present in the environment follows the transformations:
    - under certain wavelengths (100-240 nm) it splits the O_2 into O + O which, combining with the other O_2 present, form O_3;
    - under other wavelengths (240-315 nm) the O_3 are transformed back into O_2 and O, restoring the initial equilibrium.

The 4.0 machine detects, by means of a remote sensor (positioned in the most distant corner of the room from the machine), the concentration of ozone, continuously modulating the production of the gas in consideration of the volume of the room, the environmental geometry and the possible dispersions. This maintains the concentration of ozone for the time necessary to the sanitization. After that, the machine completes the cycle restoring the livability conditions of the treated rooms. The technologies proposed

(UVC and ozone), of equal effectiveness, have different characteristics and applications: UVC rays act by radiation in proximity, in a few minutes (they do not cross surfaces, mattresses and sofas). They are suitable for quick sanitization between the use of one patient and the next. Gaseous ozone takes a bit more time (according to the concentrations required and tabulated timing), but has the ability to sanitize the entire environment, not stopping on the surfaces and deeply penetrating fabrics and mattresses. It is therefore suitable for a thorough sanitization at the end of the shift.

Fig. 1. UVC lamps

The main strengths consist in the possibility of dry sanitization without leaving residues (it does not require cleaning after treatment), free of harmful and permanent substances in the environment, continuous (part-time use of an operator assigned to other tasks), compatible with desks and bookcases (does not damage electronics, paper and furnishings), fast, economical (costs less than vaporized substances, which are a daily expense and costs less than sanitization performed by external companies, being designed for energy saving (low consumption starting from 14W), and it is a safe sanitization. In synthesis, to reach the goal of a sanitation capable of effectively and efficiently combating the problem of hospital infections, the authors identified the need to proceed with a capillary and systematic intervention, fully covering each area of the operating block. For this reason, the block has been divided in 5 areas: 1) access, 2) filter rooms, 3) operating rooms, 4) sterilization room, 5) air conditioning system. Optimal sanitization processes were studied for each area in consideration of the specific needs, such as illustrated in the following. Please see references number [9], [10], [11], [12], [13], [14], [15], [16], [17], [18], [19], [20], [21], [22], [23], [24], [25], [26], [27].

3.1 Sanitization of access to the operating block

People (medical and nursing team, operators, cleaning personnel, maintenance workers and patients) and things (medical aids, drugs, machines, products, ...) necessarily have almost continuous access to the operating block. The block requires higher hygienic conditions than the rest of the structure and must be protected from pathogens, viruses, bacteria, molds, fungi, spores, insects and even rodents. Consequently, the access to the block is configured as a critical gateway to the hygienic preservation and, therefore, it is vital to ensure the sanitization of each entering element. For this purpose, action is taken both on people (by means of the restricted transit on a sanitizing platform with emission of UVC rays) and on things (by conveying them through a tunnel, in which they slide on a belt while irradiated with UVC rays).

3.2 Sanitization of the "filter room"

Access to the operating rooms is possible only through a small room in front, called filter, characterized by two sliding doors (positioned upstream and downstream of the filter) with the purpose of separating the operating room from any upstream process step. In the filter, in fact, the staff abandons clothes and footwear from outside and wears clean clothing. The identified risk obviously consists in cross-contamination during the change of clothes and shoes which, contaminating the floor of the filter, causes the clean shoes worn by the staff to lose the sterility. Same for the clothes, stored in lockers, which gradually get dirty. For this purpose, it is proposed to intervene on the filter room with an almost continuous sanitization process, by means of a double sanitization intervention: during normal activity by means of UVC rays (kept in operation after of each transit) and, after the end of each shift, by using gaseous ozone.

3.3 Sanitization of operating rooms

In literature there are many examples of infections, even serious ones, contracted by patients in the operating rooms. With reference to the chapter previously treated on hospital infections, unfortunately, the event is not uncommon. It shall be considered, as reported, that hospital infections, due to continuous pharmacological attempts to counter them, are particularly persistent, dangerous and difficult to heal. For this purpose, it is proposed to intervene on the surgery with an almost continuous sanitization process through the use, appropriately combined, of UVC rays (quick sanitization at each use) and ozone (complete sanitization at the end of each shift).

3.4 Sanitization of the sterilization room

The sterilization process of the surgical instruments leaving the operating rooms consists mainly of two phases: washing and sterilization. The washing phase involves the "dirty" area of sterilization in which the operator performs the following activities: 1) transfer of the surgical instruments from the tray to the washing tank; 2) soaking in sanitizing liquid; 3) rinsing. The sterilization phase involves the "clean" area of the sterilization in which the operator performs the following activities: 1) wrapping and sealing the surgical instruments; 2) autoclaving; 3) deposition of wrapped surgical instruments. The sterilization room, in the dirty area, presents an important risk phase for the operator who, statistically, is subject to the likelihood of being punctured and cut with the surgical instruments, during the washing phase. This means, for the operator, exposure to the risk of contracting serious diseases such as, HIV and Hepatitis. For this purpose, it is proposed to intervene on the sterilization room with a "hand free" sanitizing machine specially engineered for the purpose, to be placed upstream the washing phase, to sanitize the surgical instruments before the contact with the operator. The characteristic phases of the sanitization process operated by the machine are: a) loading of the tray coming from the operating room; b) rinsing the surgical instruments without having to touch them (the machine receives the tray directly); c) high pressure pre-wash; d) UVC treatment. It shall be specified that the 4.0 machine does not replace the current sterilization procedures but is integrated in current process.

3.5 Sanitization of the air conditioning system

The air conditioning system generates, notoriously, a risk phase for the spread of pathogens from one room to another. Viruses, bacteria, molds, fungi, spores, insects and rodents tend to lurk in the ventilation ducts and, part of them, in the filters. The cleaning of the filters, in turn, presents other risk phases such as incorrect timing of sanitization, incorrect sanitization and the operator contact with contaminated filters. According to a basic principle of resilience, it is proposed to exploit this weakness as a critical factor for success, e.g., to use UVC rays to keep the pipelines sanitized, thus drastically reducing the opportunity for contagion from room to room and, not less important, using the ducts as a vehicle for gaseous ozone, during the rest shifts, to sanitize the entire operating block (no bulky machines to move among the room). For this purpose, it is proposed to intervene on the rooms with a sanitization system based on the double technology previously described. Nevertheless, the configuration for this specific application is different: UVC rays are installed inside the ducts (cycle operation), while the ozone machine is installed upstream of the ducts, in this way by exploiting the ducts for the distribution of ozone in the rooms (operation at the end of the shift, with rooms evacuated). The ozone produced will be disposed-off by reversing the Chapman-cycle, before re-populating the rooms.

4 Technical and methodological details

A UVC-Ozone machine equipped with 12 lamps of 14W/each is able to sanitize an environment of 100m^3 in 20 minutes, conducted by an operator who can simultaneously manage 2 machines used in contiguous rooms. The activities carried out are positioning, switching on and shutdown. These tasks are normally assigned to the cleaning personnel, as part of normal activity (as written, 20 minutes at the end of each shift).

5 Economic analysis (on a case study)

An operating block on 4 floors of 250sqm/each is considered. Each floor is divided into 15 rooms, 5 bathrooms and an access corridor. For the sanitization of each floor, 2 machines costing € 4,000/each will be used, with a total investment of € 32,000. The pure cost of sanitizing the entire block, as seen in Fig. 2, is € 27.

Cost per treatment (full building)			
Electricity consumption per lamp	14	[Wh]	B
Llights on per machine (at the same time)	12	[#]	C
Electricity consumption per machine	168	[Wh]	D=BxC
Electricity consumption per machine	0,168	[kWh]	E=D/1.000
Cost per kWh	0,2	[€]	F
Operating time (2 machines)	20,0	[h]	A
Electricity cost per treatment	0,67	[€]	G=ExFxA
Machine directly operating time	10,0	[h]	K
90%, Efficiency saving (along treatment)	-9,0	[h]	H= -Kx90%
4%, Operator extra time (move, setup)	0,4	[h]	I= Kx10%
Operating time (1 man + 1 machine)	1,4	[h]	L=K+H+I
Manpower general cost (full cost)	16	[€/h]	M
Manpower cost per treatment	22,5	[€]	N=LxM
Maintenance cost (8 machines for 6Kh)	4,0	[€]	J
Total cost per treatment	**27**	**[€]**	O=G+N+J

Fig. 2. Cost per treatment

Considering a payback time of one year, the cost of an intervention is € 61, because 2 shifts / day are performed for 15 days / month, with a total of 360 sanitizations / year. The impact of the investment on each sanitization in the first year is 12,000€ / 360d = 34€, so the cost of a sanitization of the entire structure in the first year is equal to 27€ + 34€ = 61€, a cost that from the second year drops to 27€. This figure should be compared with the current € 1,500 / sanitization paid to external companies. The case study demonstrates the indisputable advantages of the proposed system compared to traditional technologies: absolute sanitization in a short time, negligible costs, no use of chemicals, environments that can be readily re-inhabited at the end of the treatment. The machines require, as a single maintenance intervention, the replacement of the lamps and minor accessories every 12,000 hours of operation, with a cost of maintenance of € 9,600 (total cost for 8 machines, 2 per floor). The useful life of a machine is estimated at 20 years. The incidence of maintenance, in this case study, amounts at 4€/treatment, as it can be seen in Fig. 2.

6 Conclusions

Thanks to what has been made available by Engineering 4.0, the authors conceptualized, developed and created a range of 4.0 machines that, used according to the approach proposed, allow to effectively combat the devastating hospital infections that today are causing many deaths of patients in transit through operating blocks. This was the first step towards a 4.0 concept of the entire operating block, safer for staff and patients. The washing and sanitizing machine described in paragraph 3.4 is another intervention carried out by the authors in this direction. They are working intensively on this and soon the operating block 4.0 will be available for an industrial level realization. At this point, the authors will have achieved the goal they set when they dedicated to this study, which is to make a contribution to medical colleagues, to alleviate the suffering to which our humanity is subjected every day.

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