Final Remarks and Perspectives on the Management and Treatment of Hospital Effluents

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Abstract This final contribution highlights the main findings resulting from past studies on the characteristics, management, treatment and environmental implications of hospital effluents. Milestone investigations have been international projects (among which Poseidon, Pills, Nopills, Neptune, Knappe, ENDETECH, and PharmDegrade) as well as specific studies suggesting adequate treatments for the effluents of new hospital facilities or the upgrade of existing treatment plants with the aim of removing targeted pollutants occurring at extremely low concentrations (ng/L to μg/L). The different strategies in managing (a separate or a combined treatment) have been discussed and the debate on the current best technologies (conventional technologies + end-of-pipe treatments or advanced biological and chemical processes) is outlined through the presentation of specific full scale treatment plants. The new frontiers in the treatment of hospital effluents are shown by presenting ongoing lab and pilot scale investigations in different countries.

What we expect in the near future are new findings regarding the occurrence and removal of new targeted pharmaceuticals, antibiotic resistant bacteria and genes, environmental risk assessment of the mixture of substances and with regard to chronic exposure, improvement in the removal of (well-known and new) targeted compounds by tested treatment trains.

Keywords Ecotoxicity, Hospital effluent, Knowledge gaps, Management, Micropollutants, Research needs, Treatment

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1 Lessons Learned

This final chapter summarizes the lessons learned from past studies and investigations on the basis of the issues addressed in the different contributions collected in this book.

A huge boost to the debate on the occurrence of pharmaceuticals in hospital effluents, their management and proper options for their treatment as well as the environmental risk assessment posed by their residues, was given by international projects (such as Poseidon, PILLS, Nopills, Neptune, Knappe, ENDETECH, and PharmDegrade), as well as international collaborations among research groups that shared their competences and interests, research in collaboration with Water Cycle Boards, effluent discharge authorization bodies, and hospital technical direction staff, all interested in improving their knowledge of hospital wastewater characteristics, management and treatments.

We know that it is not easy to obtain authorizations to sample hospital wastewater and the influent and effluent of treatment plants receiving hospital effluents, in order to look for compounds that are generally still unregulated. Other challenges that past research has faced are related to the following issues: the monitoring of a representative selection of pharmaceuticals, analysis of uncertainties in direct measurements; acquisition of consumption data of pharmaceuticals within some healthcare facilities as well as in the corresponding catchment area in order to evaluate predicted concentrations and – knowing the flow rate – to make a comparison between the respective load contribution; analysis of the sensitivity of the adopted predictive model investigations on different options of treatment (dedicated or combined); advanced or conventional treatments at a lab and pilot scale; discussion of full scale treatment trains for the specific treatment of hospital effluents; and the environmental risk assessment in terms of risk quotient as well as OPBT (occurrence, persistence, bioaccumulation and toxicity).

Most of this research was carried out in Europe, Australia and in North America, although Asia, Africa and South America were also involved, demonstrating that increasing attention has been paid worldwide to this multi-faceted topic.

Focusing on European experiences, a special reference must be made to the Bellecombe pilot site (reported in many contributions). This is a case study of excellence, located in the Haute-Savoie, France. It involves a hospital (450 beds), which opened in February 2012, a treatment plant with two distinct treatment trains allowing separate treatment of the hospital effluent and the treatment of the surrounding area (20,850 inhabitants), and a receiving surface body, the Arve river. This site represents an observatory and a support for international research programs, defined by local organizations – dealing with water and hospital management – as well as legislators, industries and scientists [1].

This book collected the results of long, demanding multidisciplinary studies carried out worldwide starting from international projects to national or regional studies related to the necessity of tackling the problem of the pollutant load of a health-care structure effluent or the treatment of the effluent of a new hospital facility in a rural or peri-urban area [8]. It also presented the viewpoint of the different actors involved in the monitoring of pharmaceuticals and other emerging contaminants in hospital effluents, management and treatment of hospital effluents, environmental risk assessment: biologists, epidemiologists, environmental engineers and chemical engineers, legislators, planners and decision makers.

2 Hospital Effluents: Regulated or Unregulated Wastewater?

There is disparity in regulating the effluent of a health-care facility from one country to another. Generally, no regulation exists for this kind of wastewater. It is often considered to be of the same pollutant load as domestic wastewater and only in a few countries is considered an industrial effluent and specific authorizations and periodical monitoring are required. Sometimes local regulations require pre-treatment of the hospital effluent (generally a simple disinfection). It can then be released into public sewage and conveyed to a municipal wastewater treatment plant where it undergoes the same treatments as urban wastewater. A picture of the current available legislations in some European and Asiatic countries is presented and discussed in the book, as well as the guidelines set by the US EPA and World Health Organization for the management of hospital wastewater. In particular, those provided by the World Health Organization in “Safe Management of Wastes from Health-Care Activities” (1999 and their revised version published in 2014) [2] highlight the risks related to liquid chemicals, pharmaceuticals and radioactive substances, recommend pre-treatments of hazardous liquids, a set-up of sewerage systems for health-care structures, minimum treatments (primary, secondary and tertiary, i.e. disinfection) and removal efficiency for selected pollutants (e.g., 95% of influent bacteria). These should be the reference guidelines for a “minimum” and sustainable management and treatment of hospital effluents in each country without specific regulations.

As the number of potential targeted micropollutants occurring in the effluent is extremely high, a selection is advisable. In this context, prioritization methods are useful tools for both regulation and surveillance purposes in the environmental policy of pharmaceuticals and other emerging contaminants. Different approaches can be used, leading to a different ranking of priority compounds. The book presents and discusses the results obtained, by following (1) an environmental risk assessment based on the risk quotient (the ratio between measured or predicted concentrations in hospital effluents and the corresponding predicted-no-effect concentration) and (2) the occurrence-persistence-bioaccumulation-toxicity (OPBT) approach for the administered pharmaceuticals in different facilities. Differences were observed between different countries and hospitals. Based on the analysis carried out, priority compounds generally include antibiotics (ciprofloxacin, amoxicillin, piperacillin and azithromycin), the anti-inflammatory drug diclofenac, the hormone estradiol and the antidiabetic metformin.

At EU level, there are no regulations concerning micropollutants in hospital effluents, but with regard to pharmaceuticals in water compartments, EU Decision 2015/495 [3] proposes a "watch list" of substances for Union-wide monitoring including the analgesic diclofenac, the hormones estrone (E1), 17-β estradiol (E2), 17-α ethinylestradiol (EE2), and the macrolide antibiotics erythromycin, azithromycin and clarithromycin. This list is periodically revised and the compounds will either be included in or excluded from a priority list of substances to be monitored.

3 Compositions of Hospital Wastewater: What We Know and What Remains Unknown

Conventional pollutants in hospital effluents have been thoroughly investigated in the past and the variability in their concentration is fairly well known. With regard to micropollutants, concentration collection has developed over the years, covering a wider spectrum of substances, but for some of them there is still little available data, due to difficulties mainly in sampling and chemical analysis.

The first review on hospital effluent characterization was published in 2010 [4]. The collected data concerned only 40 emerging contaminants (mainly pharmaceuticals and detergents) whose concentration range was compared to that observed in urban raw wastewater, and resulted higher in hospital effluents than in urban ones for some compounds. Despite the widespread prominence given to detecting the most targeted compounds (the so-called *Matthew Effect* discussed in the volume Preface), in the following years, many other substances have been monitored, as well as some of their metabolites and transformation products. This was the result of the development of new analytical techniques and increasing awareness of enlarging the spectrum of monitored micropollutants in the hospital water sample (and in the water compartment in general). Some classes, such as antibiotics, were more often investigated due to their antimicrobial properties and their role in the propagation of resistance, and to the fact that they are one of the most hazardous pharmaceutical classes for the aquatic environment.

The influence of the sampling mode (grab or composite – and in the latter case flow-, time- and volume proportional in the defined temporal unit) and frequency (number of samples during the observation period) on the reliability and representativeness of direct measures was thoroughly investigated and suggestions for planning the experimental campaign for the monitoring of hospital effluents were provided. Another approach has been suggested to avoid the many difficulties associated with the sampling of hospital water (authorization to take samples, definition of sampling mode and frequency, sample conservation and analysis): the adoption of predictive models based on pharmaceutical consumption data, human excretion factor and water volume used within the health-care facility. In this case, other challenges must be tackled: data acquisition for pharmaceutical consumption, human excretion, and consumed water. Again, uncertainties affecting these data should be estimated in order to evaluate the accuracy level of the predicted concentrations.

An interesting issue addressed in the book is the ecotoxicity of hospital effluents, strictly related to the wards, diagnostic activities and services (laundry, kitchen) within the health-care facility. It was found to be higher than in an urban effluent, varying during a day and a full year of activity. With regard to the environmental risk posed by the hospital effluent, a "single substance" approach was often used by researchers and, more recently they investigated the so-called cocktail effect linked to the occurrence of a mixture of substances in the effluent which may exhibit additive, synergic and antagonist effects. Future research will concentrate on more in-depth investigations of hospital effluent ecotoxicity and will consolidate the methodologies of ecotoxicological risk assessment adopted so far.

In this context, occurrence and environmental implications were given for three classes of compounds largely administered in hospitals: contrast media, antineoplastics and antibiotics. The first group includes biologically inactive substances, with a high excretion factor and low ecotoxicity. The second one regards extremely hazardous compounds, designed to kill or to cause severe damage to cells. It emerged that mixtures of anticancer drugs in hospital samples possess an important toxic effect, even higher than that expected by the addition of the toxicity of the individual drugs [5]. Finally, the focus on antibiotics highlights that the group includes compounds with a high worldwide frequency of occurrence in hospital effluents and the potential development and release of antibiotic-resistant bacteria (ARB) and genes (ARG) [6]. According to the WHO, the emergence and spread of ARBs has been classified one of the biggest threats to public health in the twenty-first century.

In the near future, studies monitoring anitimicrobial drug usage and resistance will allow the identification of trends and improve the environmental risk assessment, in order to establish a link between anitimicrobial usage and antimicrobial resistance and to unravel the pathways involved in the spread of ARGs [7]. Moreover, efforts will be required in investigating the chronic effects of the mixture of compounds on the environment.

4 Management and Treatment: What Is Sustainable and Correct?

The selection of a separate treatment of the hospital effluent or a combined treatment with the local urban wastewater (due to the hospital surrounding area) is strictly related to the contribution of hospital and urban settlements to the hydraulic and pollutant loads (in terms of macro- and micropollutants) [8].

The presentation of case studies allows identification of the best practices in designing and managing a hospital facility: separate collection of rain water, adoption of strategies aiming to limit water consumption within the hospital, smart organization stocks of pharmaceuticals to avoid waste, and the correct disposal of left-over (and expired) pharmaceuticals. These will result in a lower quantity both of water and pollutant load, which will require less energy and lower financial costs for the adoption of additional treatments.

Technologies adopted in full scale plants for the specific treatment of hospital effluents are always multi-barrier plants including pretreatments, membrane bioreactors and advanced oxidation processes (mainly O_3, O_3/UV and granular activated carbon GAC). Due to the high variability in the chemical, physical and biological properties of the targeted compounds, different removal mechanisms have to occur, in order to promote their removal. The book provides an overview of the current full scale treatment plants in operation in European countries, resulting from complex pre-tests aiming to identify the most adequate technologies, as well as their operational conditions to optimize removal efficiency. This selection was also influenced by local legal, economic and environmental constraints.

It is important to observe that in some European countries, centralized treatments are preferred and in a few cases, moves to upgrade the existing ones have been planned and are underway. In this context, Switzerland was the first country that decided on a national level to upgrade municipal wastewater treatment plants. Based on plant capacity, effluent/dry-weather stream flow relation and sensitivity criteria, the Swiss government identified 100 out of 700 wastewater treatment plants that will be upgraded with a post treatment step, such as activated carbon or ozone within the next few years. Currently, there are six plants in Switzerland with a post-treatment step either in operation or at a planning phase. The majority, i.e. two-thirds, apply ozone, while the others are equipped with PAC to guarantee an average removal of organic micro-pollutants of 80% (according to the so-called Micropoll strategy).

With regard to hospital effluent management and treatment outside Europe, conventional technologies are nearly always adopted, mainly including pretreatments, activated sludge processes, and chemical disinfection. In Brazil, anaerobic reactors are used in different cases, as well as an aerobic biofilter as a tertiary treatment. In China, after the SARS outbreak, activated sludge systems were replaced by membrane bioreactors (equipped with ultrafiltration membranes) in many plants, in order to guarantee greater removal of microorganisms. Treatment is completed by chlorine disinfection.

In some countries, less effective treatments are still present, including ponds and other natural systems (constructed wetlands).

Innovative treatments are under investigation on a lab or a pilot scale and are based on the use of fungi grown in pellet form, or particular membranes: membranes with immobilized fungal laccase, submerged sponge ones, membranes for nanofiltration or reverse osmosis and seem to be quite promising in removing targeted compounds. Increased interest towards advanced technologies can be seen in Brazil where they have been testing photo Fenton applications.

More recently, attention has also been paid to the removal of ARG and ARB from the hospital effluent [9]. The Pills project highlights that the risk of the spread of resistance to specific antibiotic molecules is higher in hospital effluents than in urban wastewater. The efficiency of advanced biological and chemical processes varies in the range of 1–5 log units. Ultrafiltration membrane bioreactors guarantee a consistent reduction of this risk, whereas a following step including ozonation, sand or powder active carbon filtration does not contribute to a further reduction [10].

In the near future, planning proper measures able to manage and treat hospital facility effluents will guarantee good removal of a wide spectrum of compounds with extremely different characteristics, as well as an abatement of ARG and ARB; the adoption of sustainable and economically friendly methodologies; reliable and tested technologies and containment of investment and operational costs. These actions are strictly related to the development of technologies currently under investigation and the results of more complex environmental risk assessments combining the different aspects previously discussed. Environmental risk assessment studies must also consider the risks of long-term exposure to sub-acute levels, as well as the risks of cocktails of pollutants in the aquatic environment and also their metabolites and transformation products.

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