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ORIGINAL RESEARCH REPORTS

Status of Toxicology Education in US Doctor of Pharmacy Programs

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Abstract

Purpose: **Pharmacists play a significant role in toxicology from research to clinical practice. Adequate toxicology content coverage is expected in the curricula of US PharmD programs. The purpose of this study is to evaluate the status of toxicology education in the professional PharmD programs in US schools and colleges of pharmacy.**

Method: **The websites of 142 pharmacy programs were visited. Pages with PharmD curriculum, course catalog, student handbook were identified and retrieved. The toxicology course titles and catalog descriptions were compiled and uploaded into the qualitative data analysis software, NVivo® 12. A word cloud analysis of the toxicology course descriptions was conducted. Standard data coding strategies were employed for the thematic analysis of the course descriptions.**

Results: **Toxicology content integrated with other biomedical sciences was found in 108 (78%) pharmacy programs. Standalone toxicology required courses and didactic elective courses were identified in 21 and 34 programs, respectively. The number of semester hours dedicated to the stand-alone toxicology courses varied from 1.0 to 4.0 (median = 2.5, mode = 3.0, mean = 2.7). The thematic dimensions related to toxicology in the titles and the course descriptions included acute and chronic toxicity of drugs, drug overdoses, drug−adverse reactions, poisons, diverse types of toxicants, toxicological manifestations, detection of toxicants/clinical assessments, and prevention/management of poisoning.**

Conclusion: **Most of the pharmacy programs integrate toxicology within biomedical science courses while a smaller proportion offer standalone courses either as required or elective courses. Our study may be a useful guide for pharmacy schools/colleges to review toxicology content offerings.**

Keywords: Toxicology education, Pharmacy, Curriculum, Drug-toxicity, Poisoning

1. Introduction

Exposures with industrial chemicals, pharmaceuticals, and environmental toxicants present significant health hazards to the general population. The 2019 Annual Report of the American Association of Poison Control Centers (AAPCC) National Poison Data System (NPDS) reported a total of 2.14 million human poison exposures. One poison exposure is reported to U.S. poison control centers every 14.9 s [1].

The field of toxicology is increasingly recognized as an integrative field that plays a critical role in health professions [2]. Toxicology is a combination of basic and clinical sciences such as chemistry, pharmacology, and medicine that involves the study of the toxic effects of chemical substances on living organisms [3]. The core content of clinical toxicology focuses on the principles of toxicology, toxins and toxicants, clinical spectrum of toxicity or poisoning, assessment of risks, diagnosing and treating patients with poisonings from drugs or other environmental toxic substances [4,5].

Pharmacists play a significant role in toxicology from research to clinical practice because of their in-depth understanding and training in pharmacology, medicinal chemistry, pharmacokinetics, and therapeutics [6,7]. With their in-depth knowledge of drug

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chemistry, metabolism, mechanisms of action, and drug adverse effects and being the most accessible health care professionals, pharmacists can potentially provide toxicologist service [7]. Pharmacists with toxicology expertise have a wide array of career opportunities including poison control centers [8], hospital emergency departments/care units, and intensive care units [9]. Given the indispensable role of pharmacists in the field of toxicology, the ACPE within Standards 2016 Appendix 1 included the requirement of toxicology content coverage including pharmacodynamics, mechanisms, prevention, and treatment of the toxic effects of drugs and poisons, including poisons associated with bioterrorism in all PharmD programs [10]. Similarly, Area 3 of the North American Pharmacy Licensure Examination Competency Statements includes elements pertaining to toxicology, adverse drug effects, or overdose further highlighting the continued necessity of toxicology education for pharmacy students [11].

There is limited literature on toxicology instructions in medical school curriculum [12–14]. There is no Liaison Committee on Medical Education (LCME) requirement for specific curricular elements focusing on toxicology [15]. In a recent article, Buchanan et al. indicated a clear need for additional education around toxicology in medical schools [12]. Similarly, a literature search of the last two decades resulted in a few articles related to toxicology education for pharmacy curriculum [16–21]. The objective of the study is to assess the status of toxicology education in the professional PharmD programs in the US schools and colleges of pharmacy.

2. Methods

2.1. Data collection

The websites of 142 US schools and colleges of pharmacy were searched for pages with curriculum, student handbooks, and courses catalog descriptions. Toxicology course/content information was identified and retrieved during the search process by using keywords such as “toxicology,” “toxins,” “toxicants,” “poisons”, “toxicology courses”. Courses were included in the study if the word “toxicology” or the aforesaid terms commonly used to signify toxicology were identified in the course titles and/or course catalog descriptions.

The information gathered from website search included whether the course was delivered as standalone or integrated with another course, a required or an elective course in the curriculum. Additionally, dedicated credit hours for standalone toxicology courses and professional years of course delivery were recorded. The data of credit hours are presented in this study as semester credit hours. For conversion, 1.5 quarter credit hours equaled one semester credit hours and 1.2 trimester credit hours equaled one semester credit hour. Demographic information collected included the program length and whether the program was private or public.

2.2. Data analysis

The citation frequency of words in the course catalog descriptions was determined using NVivo Word Query functions. In this analysis, conjunctions, prepositions, articles, and other nonsignificant words were excluded using the “stop words” function in NVivo. Furthermore, the counts of words with same meaning and singular or plural forms were combined using “stemming”. The citation frequency analysis included multiple occurrences of a single word or phrase in a given statement. For thematic analysis of the course descriptions, inductive qualitative analysis was employed involving standard data coding strategies [22,23]. The relevant keywords were free-coded and grouped into various thematic categories based upon similarities among the units of analysis. The classification process continued until no more new information was revealed. Initial coding and theme generation were performed independently by two investigators. An iterative review process involving another investigator was used to further clarify themes.

All the data was entered into a Microsoft Excel spreadsheet, and the descriptive statistic was utilized to analyze the data. The z-test (Social Science Statistics, Quick Statistics Calculators) was used to statistically assess the differences in offering toxicology courses between public and private programs, as well as between four-year and three-year programs. The American University of Health Sciences Institutional Review Board did not review this work since it did not qualify as human subject research.

3. Results

Of 142 US pharmacy programs, 111 (78%) programs were identified to offer toxicology content either as required core courses or integrated with other courses. Based on the textual analysis of the course titles and catalog descriptions, integration of toxicology content was identified in 107 programs (75%). Toxicology content was identified to be offered as required core courses in 21 programs.

Forty-four programs offered didactic elective courses and 15 programs were identified to offer advanced pharmacy practice experiences (APPE) elective rotation on toxicology (Table 1). The most common courses with integrated toxicology content include pharmacology, pharmacotherapeutics, medicinal chemistry, and immunology (Table 2).

Data were further evaluated to identify differences between public and private programs, and between four-year and three-year programs (Table 1). Toxicology standalone didactic core courses are offered more in public programs (n = 13, 19.4%) than private programs (n = 8, 11%). Similar trend is observed in four-year programs (n = 19, 15%) versus 3-year programs (n = 2, 11%) in offering core standalone didactic toxicology courses. Toxicology didactic elective courses are offered more in private programs (n = 30, 40% than public programs (n = 14, 20%) (p = 0.0139). Although there were a smaller number of three-year programs, a higher proportion of these programs (47%) offered courses with toxicology didactic elective courses compared to four-year programs (28%) (p < 0.01).

Table 3 demonstrates the course credit hours allocation in the standalone toxicology courses (core and elective courses). The number of semester hours varied from 1.0 to 4.0 (median = 2.5, mode = 3.0, mean = 2.7). We obtained information on the specific professional year in which each toxicology course was offered for 53 elective and 18 didactic core courses. Among the core didactic courses, 72% courses are offered in the first year. Regarding elective courses, 72% (n = 38) courses are offered in second year, and the rest in the third year.

The thematic analysis of the standalone toxicology course descriptions showed that the most frequently cited words were toxicology, basic, principles, drugs, environmental, mechanisms, treatment, clinical, management, and prevention (Fig. 1). The course titles and catalog descriptions were carefully read by two investigators for coding. The authors identified 58 codes (key words/phrases) describing the toxicology content in the standalone toxicology core or elective courses (Table 4). The codes describing the aspects of toxicology course were mentioned the highest (207 counts), followed by the codes describing the themes of toxicants (136 counts), toxic manifestations (62 counts), prevention/management (40 counts), and detection and assessment (18 counts). The thematic dimensions related to toxicology in the titles and the course descriptions of courses included citations of acute and chronic toxicity of drugs, overdoses, side effects, toxic effects, and drug–adverse reactions.

Table 2. Different biomedical science courses with integrated toxicology content.

Content areas integrated with toxicology	No. of courses identified
Pharmacology	35
Pharmacotherapeutics	25
Medicinal Chemistry and Pharmacology	13
Immunology	7
Pharmacokinetics	7
Integrated Medicinal chemistry, Pharmacology, Therapeutics	6
Drug Metabolism	4
Medicinal chemistry	4
Pharmacogenomics	4
Pathophysiology and Pharmacology	3
Critical Care	2
Emergency medicine	2
Medicinal Chemistry and Pharmacology	2
Nervous System Disorders	3
Oncology	2
Biomedical Sciences	1
Cellular Metabolism & Nutrition	1
Critical care	1
Drug Discovery and Development	1
Drug Information, Informatics	1
Emergency medicine	1
Environmental and Rural Health	1
Epidemiology	1
Pharmaceutical sciences research	1
Medication Therapy Management & Emergency Medicine	1
Natural Products and Nutraceuticals	1
Oncology	1
Patient Care	1
Patient Safety	1
Pharmacology and Physiology	1
Respiratory System	1
Surgery, Critical Care, Transplant	1

Table 1. PharmD programs offering toxicology content in the curriculum.

Coverage of Toxicology Content	Number of Programs offering Toxicology Content				
	Total (N = 142) n (%)	Public (N = 67) n (%)	Private (N = 75) n (%)	4-Year (N = 125) n (%)	3-Year (N = 17) n (%)
Integrated with other courses	107 (76)	51 (78)	56 (74.7)	90 (72)	17 (100)*
Required Standalone Core Courses	21 (14.8)	13 (19.4)	8 (10.7)	19 (15.2)	2 (11.8)
Didactic Elective Courses (Standalone)	44 (31.0)	14 (20.8)	30 (40.0)**	36 (28.8)	8 (47.0)
APPE Elective Courses	15 (10.5)	9 (13.4)	6 (8.0)	15 (12.5)	0 (0)

*P < 0.05 (3-year vs. 4-year programs) and **P < 0.01 (public vs. private programs).

Table 3. Course credit-hour allocation for toxicology content in PharmD programs.

Coverage of Toxicology Content	Semester Credit Hours (mean)±SD (n)				
	Overall	Public	Private	4-Year	3-Year
Required Core Courses	2.73 ± 1.95 (28)	2.50 ± 0.87 (20)	2.50 ± 0.71 (8)	2.54 ± 0.80 (26)	2.00 ± 1.00 (2)
Didactic Elective Courses	2.28 ± 0.7 (66)	2.05 ± 0.70 (29)	2.46 ± 0.73 (37)	2.30 ± 0.76 (58)	2.13 ± 0.60 (8)

4. Discussion

In this study, a web-based analysis of toxicology education across Doctor of Pharmacy (PharmD) programs in the US revealed that most PharmD programs integrate the study of toxicology within biomedical science courses while a smaller proportion offer standalone courses either as required or elective courses. One-hundred seven pharmacy programs were identified which offer a total of 136 courses with integrated toxicology content.

In contrary to the integrated coverage of toxicology in the PharmD curriculum, only 15% programs offered dedicated toxicology standalone courses in the core curriculum. Didactic elective courses focusing on toxicology were identified in 34% of the programs. Only 15 programs (11%) were found to offer advanced pharmacy practice experiences (APPE) elective rotation on toxicology. Toxicology standalone didactic core courses were offered more in public programs than private programs. Similar trend was observed in four-year programs versus 3-year programs in offering core standalone didactic toxicology courses. The presence of toxicology department or funded research programs in toxicology in public and four-year programs may have

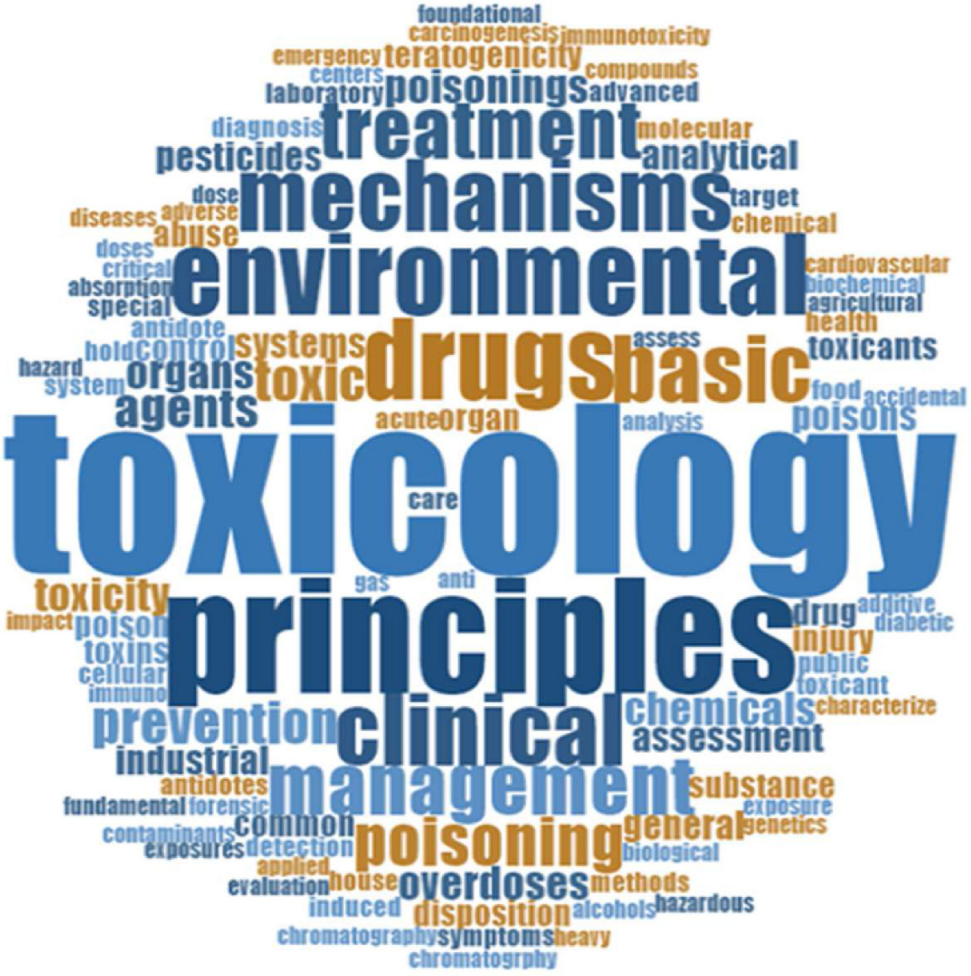

Fig. 1. Word-cloud analysis of toxicology course descriptions. The larger the font-size of a word represents the higher frequency of citations. For example, the most frequently cited words included toxicology, principles, drugs, environmental, mechanisms, treatment, clinical, management, and prevention.

Table 4. Emerging themes from the content analysis of toxicology course descriptions.

Thematic categories	Examples of textual citations	Number of citations
Aspects of Toxicology Courses	Toxicology Principles of toxicology Introduction to toxicology Fundamentals Clinical toxicology Environmental Toxicology Fundamental, Foundational Forensic Pharmacogenomics Pharmacokinetics Pharmacology	207
Toxicants or source of poisoning	Toxicants Toxidromes Toxins Chemicals Poisons Environmental pollutants Drugs, Drug overdose Household toxicants Food Pesticides Smokes Substance abuse (opioids) Recreational drugs Heavy metals Phytomedicines, plants Food additives Industrial Agricultural agents Occupational toxicants Venoms Xenobiotics	136
Toxicological manifestations	Organ toxicity Acute toxicity Chronic toxicity Mechanisms Molecular/cellular mechanisms Teratogenicity Carcinogenesis Target organs Immunotoxicity Drug biotransformation/ disposition	62
Detection and clinical assessment	Laboratory techniques Analytical techniques Spectrophotometer Chromatography Assessment, Diagnosis	18
Prevention & Management	Prevention Treatment Antidotes Management Monitoring Poison control centers Pharmacists	40

influenced the inclusion of dedicated toxicology courses in those programs. On contrary, toxicology didactic elective courses are offered more in private programs compared to public programs. Similarly, a higher proportion of 3-year programs (47%) offered didactic elective courses compared to four-year programs (28%). While 34% of the programs listed toxicology electives in their curricula, the frequency of course offering remains unknown. Because PharmD programs offer diverse elective courses and students have their preferences of choosing elective courses.

Thematic analyses of the course titles and descriptions identified the most common aspects of toxicology courses, including basic principles of toxicology, clinical toxicology, forensic toxicology, and environmental toxicology. The courses included content covering various toxicants, including drugs, drugs overdose, chemicals, poisons, household toxicants, pesticides, substance abuse, industrial toxicants, heavy metals, phytomedicines, and venoms. The standalone courses also contained content related to toxic manifestations following acute and chronic toxicity, organ toxicity, teratogenicity, carcinogenesis, immunotoxicity, drug overdoses, adverse drug reactions, drug–drug interactions with toxic manifestations, and molecular and cellular mechanisms of toxicity. Citations of other toxicology content, including the identification methods, assessment, monitoring, and treatment of poisoning, were found in several course descriptions.

The increased coverage of toxicology content as integrated with other biomedical or clinical courses in the PharmD program may result from the paradigm shift in pharmacy education introducing entry-level PharmD programs. Pharmacy curriculum reforms focusing on outcome-based, patient-centered clinical education have resulted in noticeable reductions in basic pharmaceutical and biomedical sciences [24,25]. Additionally, these changes have been accompanied by an increasing trend of curricular integration in pharmacy education [26,27]. The integrated toxicology education in pharmacy program is consistent with medical education, where there has been an effort to integrate toxicology in the emergency medicine [12,14,28,29].

There are several limitations of our study to note. First, our data collection was entirely reliant on the website of a school or college of pharmacy being accurate when the data were collected. Our data may not fully reflect the coverage of toxicology content in PharmD program as the study included data based on the citation of “toxicology” and related keywords in either course titles or course catalog descriptions. In addition, our analysis would not have been able to ascertain the depth and breadth of individual toxicology topics covered within integrated courses. However, our study may be useful to curriculum committees in deciding how and when to integrate this subject within their

institution's curricula. Further research and consideration are needed to form a consensus and determine the best approach to educating students in this subject area.

5. Conclusion

A vast majority of the pharmacy programs across the academy offers clinical toxicology as an integrated course with other biomedical and clinical courses. Only a handful of programs offered dedicated toxicology standalone courses in the core curriculum. Opportunities exist to expand the offering of toxicology content in the PharmD core curriculum. Our study may be a valuable guide for pharmacy schools/colleges or other institutions to review toxicology content offerings.

Ethical approval

The American University of Health Sciences Institutional Review Board did not review this work since it did not qualify as human subject research.

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Other disclosure

There is no conflict of interest.

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