Received: 1 July 2025 | Revised: 1 August 2025 | Accepted: 4 August 2025

DOI: 10.1002/bcp.70252

ORIGINAL ARTICLE

# Therapeutic drug monitoring education: The current state

Guenka Petrova[1,2] | Stiliyana Blagova[1] | Konstantin Tachkov[1] | Marlene Santos[3,4] | James Bluett[5,6] | Merita Rumano[7,8] | Elena Kkolou[9] | Elena Drakalska[10] | Marija Arev[10] | Mehtap Cakmak Barsbay[11] | Denis Mulleman[12,13]

[1]Faculty of Pharmacy, Medical University Sofia, Sofia, Bulgaria

[2]Research Institute of Innovative Medical Sciences, Medical University Sofia, Sofia, Bulgaria

[3]REQUIMTE/LAQV, Escola Superior de Saúde, Instituto Politécnico do Porto, Porto, Portugal

[4]Molecular Oncology & Viral Pathology, IPO-Porto Research Center, Portuguese Institute of Oncology, Porto, Portugal

[5]Versus Arthritis Centre for Genetics and Genomics, Centre for Musculoskeletal Research, The University of Manchester, Manchester Academic Health Science Centre, Manchester, UK

[6]NIHR Manchester Biomedical Research Centre, Manchester Foundation Trust, Manchester Academic Health Science Centre, Manchester, UK

[7]Faculty of Natural Sciences, University of Tirana, Tirana, Albania

[8]Faculty of Medicine, University of Medicine in Tirana, Tirana, Albania

[9]Cyprus Institute of Neurology & Genetics, Nicosia, Cyprus

[10]Faculty of Medical Sciences, Goce Delcev University, Stip, North Macedonia

[11]Faculty of Health Sciences, Ankara University, Ankara, Turkiye

[12]Center for Molecular Biophysics, UPR CNRS 4301, Nanomedicines and Nanoprobes Department, University of Tours, Tours, France

[13]Department of Rheumatology, University Hospital Center of Tours, Tours, France

**Aims:** To evaluate available information on therapeutic drug monitoring (TDM) education programmes and their implementation across different countries.

**Methods:** The study was performed in two phases. First, a scoping review of scientific literature on available education programmes was performed. Afterwards, a questionnaire was distributed among a worldwide network of professionals engaged in the practice of TDM.

**Results:** Eight scientific articles discussing TDM educational programmes were found. They described in depth an educational programme on TDM, which was primarily offered as postgraduate education programme for hospital staff. We received a total 23 responses (30% response rate); of these, 68% were from academia. For 70% of respondents, TDM is part of the educational programme of healthcare professionals, and for 56% it is offered at both undergraduate and postgraduate level, aimed mainly at physicians (39%) and pharmacists (65%). TDM is mainly performed in infectious diseases (n = 15), neurology (n = 14) and psychiatry (n = 12), as well as for antibiotics (83%), monoclonal antibodies (53%), and oncology and psychotropics (48%). Funding for TDM is derived mostly from public health insurance (48%), hospital (44%), patients (39%). In some cases, patients might co-pay to hospital or to health insurance fund.

**Conclusions:** Education on TDM is scattered across different subjects, disciplines and degrees. It is oriented essentially towards physicians and pharmacists, and its funding is mainly public. General guidelines are lacking. In light of this, it is necessary to consider developing a comprehensive educational programme on TDM, oriented towards relevant drugs and diseases, and encompassing appropriate analytical and pharmacological methods.

The authors confirm that the Principal Investigator for this paper was Guenka Petrova and that she had direct clinical responsibility for patients. There were no patients in this study and therefore the Principal Investigator Guenka Petrova is responsible for coordinating the work.

**Correspondence**
Guenka Petrova, Faculty of Pharmacy, Medical University Sofia, Bulgaria.
Email: gpetrova@pharmfac.mu-sofia.bg

**Funding information**
European Cooperation in Science and Technology (COST) is a funding agency for research and innovation networks. The work was funded under the European Network on Optimising Treatment with Therapeutic Antibodies in chronic inflammatory diseases (ENOTTA) CA 21147 project, supported by COST programme.

**KEYWORDS**
education programmes, healthcare professionals, therapeutic drug monitoring

## 1 | INTRODUCTION

Therapeutic drug monitoring (TDM), according to some authors, is the clinical practice of measuring specific drugs at designated intervals to maintain a constant concentration within the therapeutic window in a patient's bloodstream, thereby optimizing individual dosage regimens.[1,2] TDM is applied across various treatment areas, including infection diseases and new areas as rheumatology, immunology, gastroenterology and others.[3–5] It is also used during drug development through to post-marketing studies for pharmacokinetic and pharmacodynamic drug characterization, appropriate medicines selection, dosage, control, administration, patient adherence, treatment results evaluation and dosage regime adjustment.[6] Recently new terminology for TDM has been recommended as "concentration-guided dosing" to better reflect personalized dosing.[7]

TDM requires multidisciplinary cooperation and involves professionals with different healthcare and scientific backgrounds: pharmacists, physicians, biochemists, pharmacometricians and nurses.[8] Due to the plethora of clinical areas of application, education on TDM is important for a variety of professionals.[9] For pharmacists it provides information on pharmacological action, safety profile, analytical methods of medicines and cost-effectiveness or cost-utility.[10–12] For clinicians it allows for patient-level monitoring, providing insight and information on how to interpret results with respect to the clinical state of the patient and what best course of action to take, such as making the decision for dose adjustment or therapy changes.[13] Clinical laboratories have the crucial role of choosing the correct analytical method for the type of medicine in question.[14–16] Healthcare professionals other than physicians (eg, nurses or pharmacists) are involved in taking samples and administering doses, while the input from all professional fields should be used to best advise patients on how to achieve the most from their therapy, including adherence issues.[17]

TDM has emerged as a tool due to the related development and advancement of disciplines such as pharmacokinetics, pharmacodynamics and pharmacometrics, which in the 21st century have become necessary disciplines not only for methodological refinement but are also in medicines regulation.[18] Other terms and principles have been proposed, such as target concentration intervention, model-informed precision dosing and, more recently, concentration-guided dosing.[7]

### What is already known about this subject

- Therapeutic drug monitoring (TDM) is expanding its role with the development of new molecules and methods for their assay.
- Not much is known regarding the current state of educational programmes, whether such education is performed in established educational curricula, post-graduation or as specialized courses.
- There is no information about the degrees on TDM degrees.

### What this study adds

- This study explores the available information on TDM education, degrees and types of educational methods.
- It also examines the application of TDM in different countries for different diseases and medicines.
- TDM funding is also studied.

Given the role TDM has from preclinical and clinical dose adjustments to patient-level monitoring and approval of medicines, TDM education should play a pivotal role in preparing future specialists to provide up-to-date, evidence-based care for patients. However, not much is known regarding the current state of educational programmes, whether such education is performed in established educational curricula, post-graduation or as specialized courses, which provoked our interest in conducting this investigation.

The goal of this study was to analyse available information on TDM education and its implementation across different countries.

This study is part of the European Network on Optimizing Treatment with Therapeutic Antibodies in Chronic Inflammatory Diseases and the European Cooperation in Science and Technology COST Action (https://enotta.eu/) project and was performed by the authors.

## 2 | MATERIALS AND METHODS

The study was performed in two phases. First, a scoping review of scientific literature on available education programmes was performed. We then distributed a questionnaire among suggested professionals engaged in the education and practice of TDM.

The scoping review was conducted from 1 October 2024 to 30 May 2025 by searching for publications in PubMed and Google Scholar (Figure 1).[19] In addition, the reference list of the selected articles was searched, applying a snowball approach. Key search words were "therapeutic drug monitoring AND education AND program AND degree" and "therapeutic drug monitoring AND learning AND program". Scoping reviews are less demanding than systematic reviews and offer an unconstrained search approach. Additional review of the reference list enabled the selection process.

We focused on scientific publications that provided information on TDM education. We also considered information from university webpages if teaching hours and curriculum were provided, as well as information on purpose, eligible professionals and degrees. Exclusion criteria were education on model performance for TDM, assay methods and the effectiveness of TDM on disease outcomes. Selected abstracts were screened by three reviewers (SB, KT and GP) and full-text articles were included based on the focused inclusion criteria. Full texts were extracted and read by two of the reviewers (SB and KT), while the third (GP) acted as a referee in case of discrepancies.

The second part of the study involved distributing a questionnaire among professionals engaged in TDM and, if possible, representatives of TDM societies. The questionnaire was created by the project team, which included clinicians, pharmacists, biochemists, mathematicians, academic staff and researchers in a variety of medical areas. It was circulated four times for corrections and proposals on the content, and finally approved by the project team (Appendix 1). The questionnaire was digitalised to be easily and independently accessible from everywhere.

The professionals engaged in TDM were selected through personal contacts and online searches. In addition, the editorial boards of pharmacology journals were thoroughly reviewed and members with publications in the field were identified and selected by two of the authors.

All responders were informed, in the introductory section and the initial question, that the results of the questionnaire would be published anonymously. Although the responses were intended to be anonymous, participants were given the opportunity to provide their email address in the final question if they wished to be contacted afterwards.

The study did not include human or animal subjects and therefore there was no need for it to be approved by an ethical board or committee.

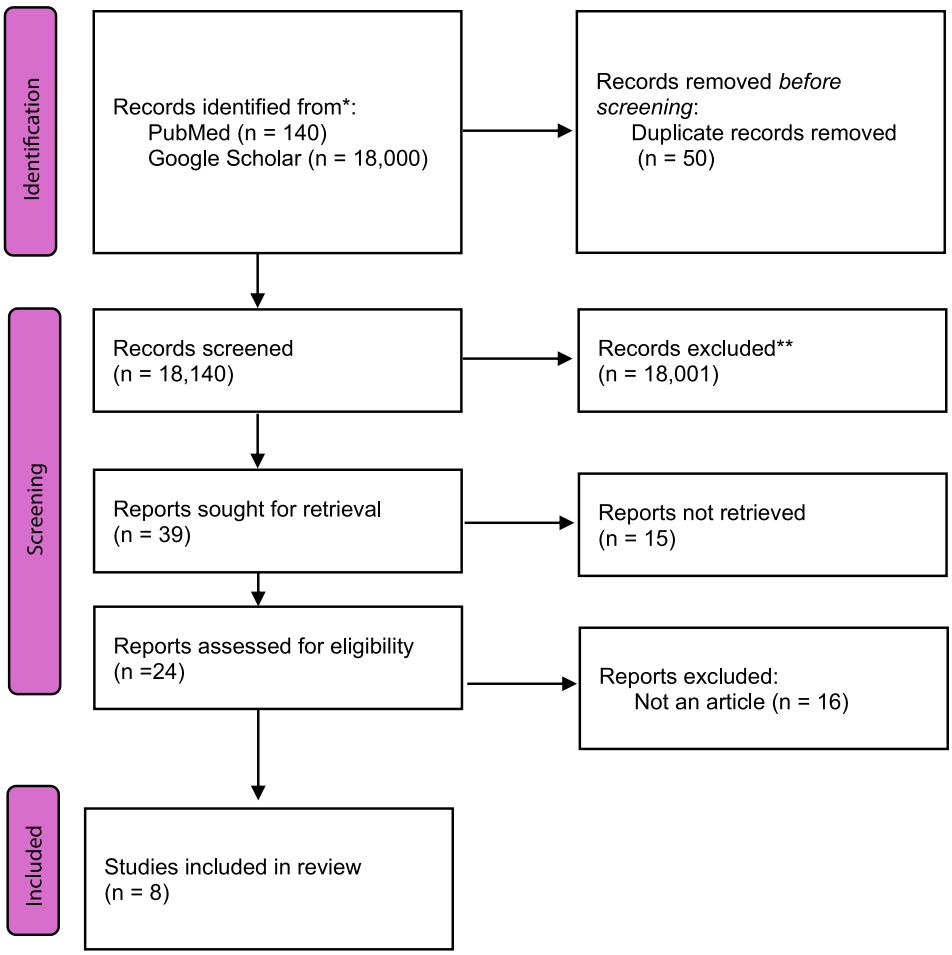


**FIGURE 1** Preferred Reporting Items for Systematic Reviews and Meta-Analyses chart for identified studies.

## 3 | RESULTS

### 3.1 | Results from the scoping review

Despite the enormous volume of sources searched, only eight scientific articles discussing TDM educational programmes were identified. The remaining articles and data sources were excluded due to nonconformity with the inclusion criteria, mainly because they did not present or discuss educational approaches or programmes for TDM (Figure 1).

The included articles described several educational approaches, ranging from undergraduate to postgraduate programmes, that were mainly offered to hospital staff to increase TDM knowledge. The main characteristics of the studies are shown in Table 1.

One programme, described by Samani et al,[22] was offered through E-learning methodology and organized within US hospitals targeting biochemists and clinicians. The educational materials covered a wide range of topics, from introduction to the significance of TDM, and the performance of TDM for various medicines. Each lecture was 30-40 min in length. Although this programme does not confer any degree, the authors reported an increase in the level of TDM knowledge of participating professionals. The programme followed the analysis, design, development, implementation and evaluation instruction design model. The design stage of the programme consisted of a detailed project plan, created with active learning strategies, patient participation and multiple learning styles such as interactive diagrams, animations and quizzes. For the development stage, specialized software was built, completed with interactive schemes, diagrams, animations and flowcharts. The implementation stage was the next step of the educational plan. At this stage, trainees received compact disks (CDs) containing information and educational resources on TDM, and all participants were given a specified timeframe to use these resources and complete follow-up questionnaires. After completion, participants underwent an evaluation process according to the article. These results were compared with an initial questionnaire and showed that the course allowed healthcare professionals to improve their understanding of pharmacokinetics and its role in interpretation of TDM. Specifically, authors concluded that healthcare professionals were more confident in interpreting TDM results and overall the education method was effective during the time it was executed.

The article by Heaton et al[26] describes TDM education practices at hospital level education in the United States. Education is provided primarily through postgraduate courses or modules and integrated into pharmacy and other healthcare professional programmes. The focus of the programmes is the application of pharmacokinetic principles to individualize drug therapy. Pharmacy, laboratory and medical students were trained to understand the pharmacokinetics of drugs, interpret drug concentration data and adjust dosages accordingly. The article emphasizes the importance of collaboration among healthcare

**TABLE 1** Published articles of TDM education fulfilling the eligibility criteria.

| Authors | Programme | Degree | Level | Academic hours of 45 min | University |
|---|---|---|---|---|---|
| **Undergraduate education** | | | | | |
| Bowers et al[20] | Course during pharmacy education | Case-based programme *vs* lecturing | Undergraduate | From 4 to 2 credits | University |
| **Postgraduate education** | | | | | |
| Cairns et al[21] | in-house credentialing programme | n/a | Postgraduate | Credential and annual re-credentialing | Hospitals |
| Samani[22] | e-learning | Course | Postgraduate | 30-40 min each lecture | Hospital |
| Firman et al[23] | Education or credentialling package delivered by pharmacist-managed TDM programme | Credentialing or education | Postgraduate | n/a | Hospital |
| Ma[24] | To develop and evaluate a framework for a TDM training programme at hospital | TDM training programme framework comprising a training module, knowledge quiz and documentation | Postgraduate | 3 weeks | Hospital |
| D'Angio et al[25] | Pharmacy-based educational intervention | in-service programmes and newsletter | Postgraduate | 1 month | Hospital |
| **Undergraduate and postgraduate education** | | | | | |
| Heaton et al[26] | Courses or subjects | Part of medical or pharmaceutical programs | Postgraduate and undergraduate | Explain US practice of education | Hospitals |
| Bates et al[27] | Different learning strategies for physicians | n/a | Postgraduate and undergraduate | n/a | University |

Abbreviation: n/a, not avaible.

professionals, including pharmacists, physicians and laboratory staff, to ensure comprehensive patient management and enhance the effectiveness of TDM postgraduate education.

The paper by Cairns et al[21] describes an innovative in-house credential programme organized at hospital level to increase the TDM knowledge of Australian pharmacists.[26] After a 1-year education involving didactic lectures, pre-reading materials, multiple choice questions and real-life clinical cases, professionals received their initial credentials. On completion of the course, professionals needed to maintain their knowledge and be approved in the annual re-credentialling education. In total, 160 pharmacists were credentialed through the initial programme and 95 pharmacists through annual re-credentialing. Although oriented only to vancomycin and aminoglycoside pharmacist-led monitoring, this education is innovative and provides credits and re-credentials.

A study by Bates et al[27] explored methods for teaching physicians about TDM. Authors recognized the value of traditional teaching approaches, such as lectures, but also highlighted the potential of digital methods in supporting learning across information systems, models and interventions at all stages of the process.[21] The implementation of a computerized support system allowed for real-time access to relevant information and aided physician decisions by providing reminders and useful information about the prescribed drugs. For instance, when ordering a TDM test, the system can display the patient's last drug concentrations and provide guidelines for the appropriate therapy. They emphasized the collaborative efforts involving various healthcare professionals (physicians, pharmacists and laboratory staff) that can contribute to the development and improvement of TDM guidelines. The article emphasized the unified approaches to TDM.

Firman et al,[23] performed a cross-sectional online survey on pharmacist-managed TDM services in Australia. They evaluated pharmacist-managed TDM programmes within Australian hospitals and healthcare settings. The programmes highlighted improved patient outcomes but had difficulty maintaining the educational packages and training. The education programme consisted of lectures with a duration of 60 min each, face to face, covering pharmacology, pharmacokinetics and TDM principles. In this TDM education programme the authors focused on the design of vancomycin-specific TDM training. The programme duration was 12 weeks and pharmacists held a postgraduate qualification. The competency evaluation included 10 questions and real-life scenarios. The participants were only hospital pharmacists and were accredited if they were approved in 100% of the questions at the first attempt. There was a significant improvement in the understanding of the importance of TDM across the survey group. The pharmacists had better understand in dosing patients, especially with renal failure, became more confident in recommending initial drug levels and effective interprofessional collaboration.

Bowers et al[20] compared traditional lectures and a case-based learning approach using virtual patients in a TDM educational course. Focus topics in TDM education were traditional antimicrobial dosing and monitoring, clinical pharmacokinetics calculation, drug dosing in renal and hepatic impairment, and the pharmacokinetics of cardiac agents, antiepileptics and anticoagulants. Despite fewer educational hours, students in the case-based learning course retained more knowledge, especially in calculation-based tasks, than those following the traditional learning format. The use of virtual patients and proactive learning proved effective, according to the article.

Ma[24] discussed a TDM training programme framework comprising a training module, knowledge quiz and documentation at hospital level for postgraduate education by using digoxin as the example drug. The study reports that education improved knowledge scores and confidence in TDM as well as standardization of intervention documentation. The training programme was designed with components of theoretical pharmacokinetics, pharmacodynamics, the main principles of TDM and clinical scenarios, practical case-based learning, interactive workshops and real-word scenarios, competency and knowledge tests, and clinical decision-making evaluations. The educational programme included 20-30 educational hours spread across several weeks.

D'Angio et al[25] described a pharmacy-based educational intervention that was based on specially prepared in-service programmes and newsletters for postgraduate students with beneficial results. The study aimed to evaluate whether an educational intervention could improve physicians' and pharmacists' knowledge skills and performance related to TDM, including interpretation of drug concentration data. The programme included lectures, case discussions and practical exercises. The educational programme substantially improved the clinical performance of healthcare professionals in TDM. This led to improved individualized patient care and more effective drug dosing.

Only one article discussed changes at the undergraduate level of education,[20] five discussed changes at the postgraduate level,[21–25] and the final two at both under- and postgraduate level.[26,27] The changes at undergraduate level were stimulated by the university authority, the changes at postgraduate education were mostly initiated by hospital authorities and the rest by both hospital and university authorities. We might assume that the practical application of TDM is the trigger of educational courses.

## 3.2 | Results from the questionnaire

We identified a total of 89 names of professionals engaged in TDM worldwide. Their email contacts were obtained from the publicly available sources and the questionnaire link was sent to all of them at least three times. Thirteen email addresses were invalid, probably because of employment or electronic address changes, resulting in 76 eligible contacts. Following this, we received a total of 23 responses, representing a 30% response rate. Questionnaires were received from almost all identified groups in the questionnaire (excluding regulators), but academia was the most representative group (68%), possibly due to the orientation of the questionnaire towards TDM education. Thirteen percent of the respondents identified themselves as physicians and as pharmacists.

Among the eight physicians, including those in academia, four identified themselves as clinical pharmacologists, while the remain were rheumatology, pharmacology, nephrology, and physiotherapy and rehabilitation specialists. Most answers originated from European

countries. Answers were received from Albania (n = 1), Belgium (n = 2), Bulgaria (n = 1), Croatia (n = 1), Cyprus (n = 1), France (n = 1), Germany (n = 1), Greece (n = 1), Italy (n = 1), North Macedonia (n = 1), Norway (n = 1), Poland (n = 2), Portugal (n = 1), Serbia (n = 2), Spain (n = 1), the United Kingdom (n = 1), Argentina (n = 1) and Türkiye (n = 1).

Almost 70% of responders answered that TDM was part of the educational programme of healthcare professionals in their country; of these 56% responded that it is organized both at undergraduate and postgraduate level, 25% only at undergraduate level and 19% only at postgraduate level. The length of the TDM education was less than one semester for 48% of responders, one semester for 9%, more than one semester for 4% and 39% answered they did not know. Two responders answered that there was a course providing a master's degree on TDM and one providing bachelor's degree, but they pointed out that this was a Master of Pharmacy degree, therefore we can consider these answers incorrect because the degree is in pharmacy and not in TDM.

Physicians and pharmacists were the professionals for which the curricula more often included TDM at undergraduate and postgraduate level (Figure 2). Biochemists and clinical chemists were the third category of professionals educated in TDM.

Answers on Figure 2 and all other are more than 100% because respondents were able to select more than one option.

According to the responses obtained, TDM is performed in a variety of disease areas where chronic diseases prevail. Nevertheless, in 15 countries infectious diseases are also an area of TDM application (Figure 3).

The categories of drugs that correspond to disease areas in which TMD is applied are presented in Figure 4.

For 78% of respondents there was no national regulation or recommendation to standardize TDM. Those who answered "yes" to the availability of national regulation or guidance pointed to the British National Formulary (UK), Recommendations by the International Association of TDM and Clinical Toxicology or the French Pharmacology Association (France), Ministry of Health (Türkiye), National Guideline of Learned Society (Germany), Practical Recommendations for the use of TDM of Biopharmaceuticals in Inflammatory Diseases (Spain), Best Practices in Clinical Pharmacokinetics, the Portuguese Pharmaceutical Society – Council of the Specialty College of Hospital Pharmacy (Portugal),[28] several Masters programmes on pharmacokinetics and TDM across universities. The availability of a guideline for other medicines but not on monoclonal antibodies reported one country (Spain). What is not surprising, but is important to note, is that professionals are using university programmes for guidelines and regulation on proper TDM performance.

In countries where guidelines are not available, the benchmarks were international or European guidelines (Bulgaria, Croatia, Italy, North Macedonia, Serbia), local or regional guidelines (Belgium), common clinical guidelines, practical recommendations, general standards of care (general medical literature), and occasionally scientific reference articles or the opinion/guidance of specialists, for example pharmacists or pharmacologist (Argentina).

The last question focused on funding of TDM (Figure 5). In most cases the funding is public, through health insurance or hospital budgets, but in eight cases patients were required to pay for TDM, as well

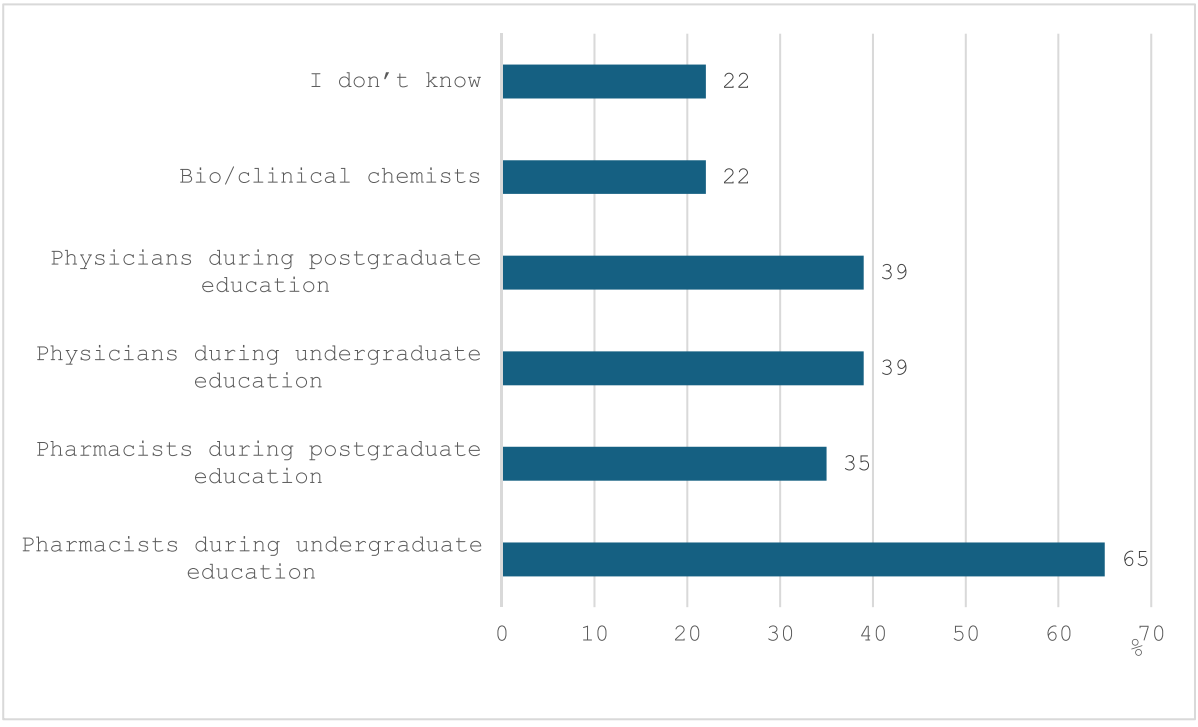


**FIGURE 2** Professionals educated on therapeutic drug monitoring. Participants could choose multiple categories of professionals.

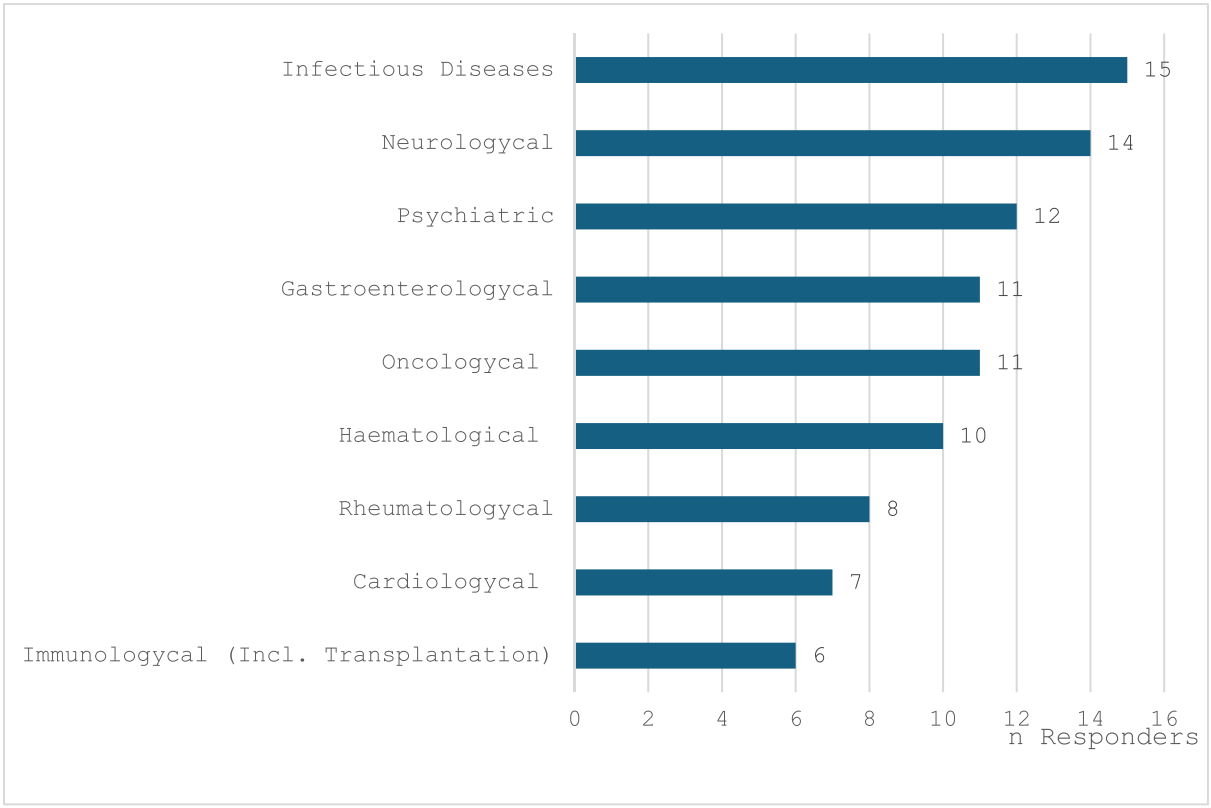


**FIGURE 3** Disease areas of interest for therapeutic drug monitoring.

as the companies producing tests (assay companies) (n = 3) or producing medicines (pharma companies) (n = 3).

## 4 | DISCUSSION

With this study we intended to explore the available information for educational programmes on TDM and additionally to analyse in which therapeutic areas and specialties TDM is practiced. The study used a scoping review approach because this is less constrained than systematic reviews and offers opportunities to explore related references in publication. A secondary methodology utilized a questionnaire research method among TDM professionals. To the best of our knowledge this is the first such study. Raising awareness about TDM education is crucial since individual dosing has a significant impact on clinical outcomes and treatment success. Moreover, TDM is widely recognized as important, but is still not widely implemented in clinical practice in many countries. Before TDM can be routinely applied, we need consensus on educational standards and best practices.

We found that scientific articles on educational programmes on TDM are scarce. Only eight articles described an educational programme on TDM, mainly for postgraduate education of hospital staff. Although a variety of approaches were considered (both systematic and narrative review), during the search process the most successful strategy turned out to be the scoping review, because of the advantages of using reference snowballing, and there were fewer constraints around the use of keywords that could lead to a larger number of articles. It is worth noting the innovative approach of in-house credentialling education, which is organized as long-life learning on a yearly basis.[21] Future generations must learn faster, receive practically oriented knowledge and constantly build on this.[29] A micro-credentials approach is extremely suitable for future generations and is an effective approach for life-long learning. It is crucial to ensure that everyone using TDM in clinical practice has the knowledge, skills and competences to do so. In its concept paper, the European commission explained that "micro-credentials certify the learning outcomes of short-term learning experiences and offer a flexible, targeted way to help people develop the knowledge, skills and competences they need for their personal and professional development".[30] To summarize, from what was found as available evidence on educational activities, we can distinguish TDM being present in three distinct situations: undergraduate, postgraduate and micro-credential approaches. Undergraduate education should be broader and more foundational, postgraduate more specific and tailored to particular medical specialists, and micro credential approaches to maintaining long-term knowledge. What could be suggested is that all levels of education must be organized on a case study basis.

Many universities include information on their webpages on TDM education in different programmes, such as pharmacists' degree programmes, healthcare professionals' degree programmes, PhDs etc.[31–34] TDM is either part of the postgraduate or of undergraduate

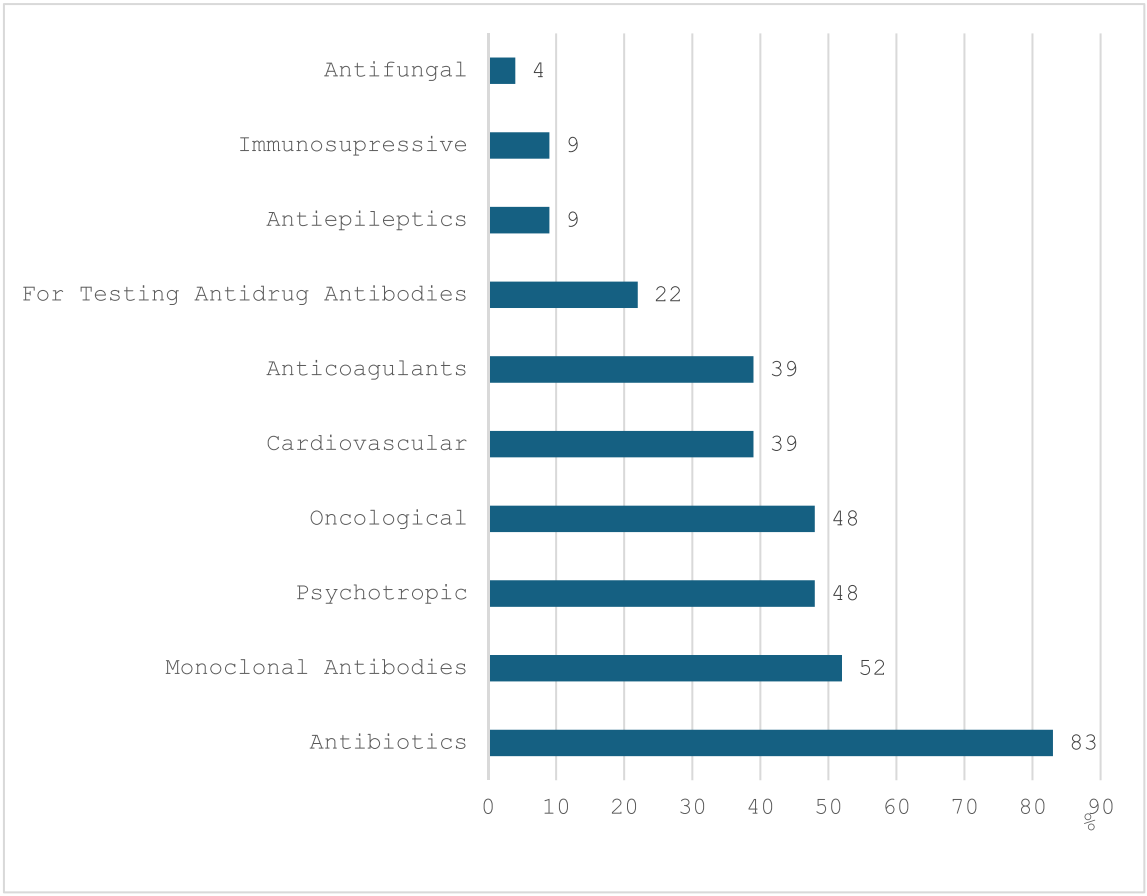


**FIGURE 4** Drugs for which therapeutic drug monitoring is applied.

education. When part of the undergraduate education of pharmacists TDM is either a separate subject or included in the pharmacokinetic programme. When part of postgraduate education for pharmacists and other medical professionals, TDM is usually a specialized course. Pharmacists might specialize in clinical pharmacy, clinical pharmacology, biochemistry and other specialties. Physicians usually specialize in different clinical areas in which they need to interpret results from TDM.[35]

The results from the scoping review were confirmed by the answers to the questionnaire. They also highlight the clinical specialties for which TDM education is provided, which are rheumatology, gastroenterology, infectious diseases, immunology, nephrology, transplantology and oncology.[36,37] Similarly, TDM is performed for antibiotics, monoclonal antibodies, psychotropic medicines, immunosuppressors, anticoagulants, antiepileptics, etc.[38,39] We assume that antibiotics were first an object of pharmacokinetic monitoring and this practice remains available in all countries, although it might not be so frequently performed in ambulatory care. TDM application is becoming more prevalent in the field of medicine, especially after the development of precision medicine, targeted therapies and patient-centred care, and this is seen in the answers to the questionnaire. Many articles discuss the results or approach of applying TDM in the disease areas or medicines mentioned on Figures 3 and 4, but there is scarce information about who is eligible for TDM education or how is this education should be conducted.[40]

In addition, our article highlights the lack of standards and uniformity regarding TDM implementation, even though for many diseases it is recommended and healthcare professionals are obliged to conduct it without proper instructions.[41] The latter is confirmed by the questionnaire results, which indicate that many countries do not have a standard to perform TDM and international (unclear which) or common clinical guidelines, practical recommendations and general standards of care are being used.

In our opinion these guidelines or available standards could be strengthened. With the appearance of many biological and biosimilar medicines it is likely that TDM will continue to be widely used. Without adequate education, standard procedures and guidelines, implementated in clinical practice, this development may be stymied. It may be time to consider the organizational and educational standards required for acquiring a professional degree in TDM and education not only on methodologies, but also on all possible disease areas of application and differences in respect to the medicines tested. That is why we added a provocative question on available education providing Bachelors or Masters degrees on TDM. We know that TDM is typically integrated into broader programmes such as pharmacology or pharmacy, rather than offered as a standalone

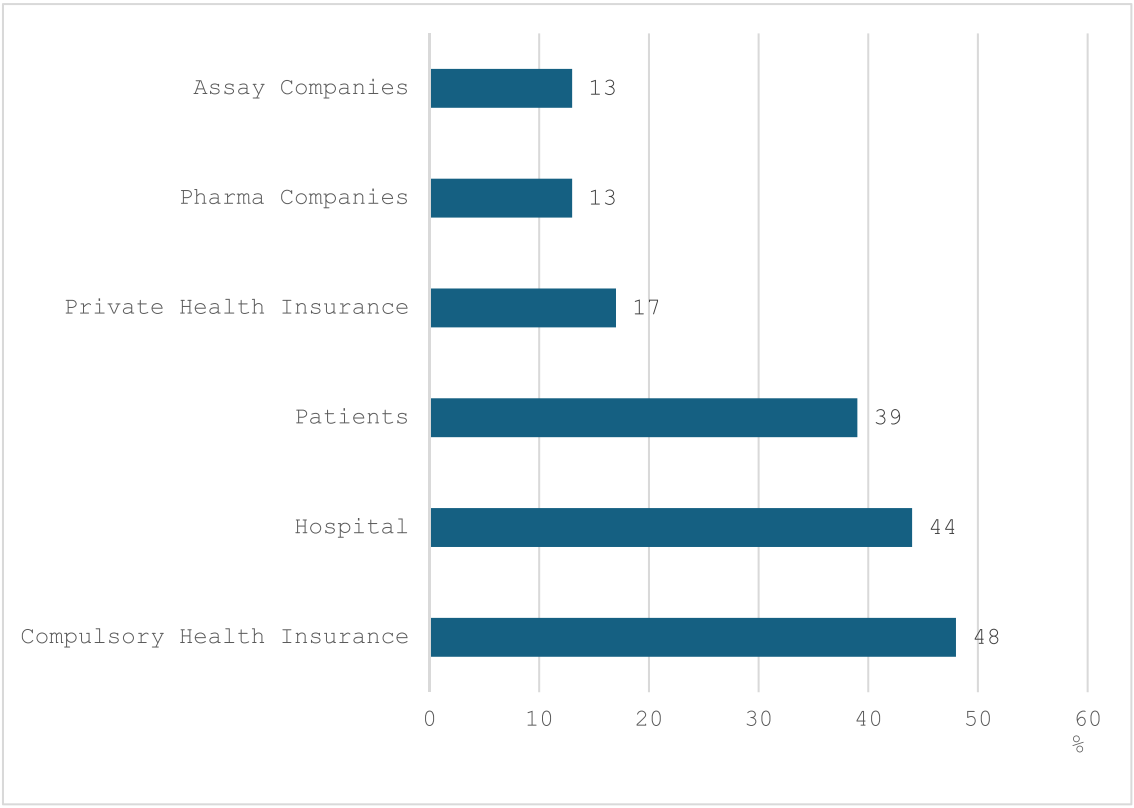


**FIGURE 5** Funding of therapeutic drug monitoring.

academic degree. However, the field has experienced tremendous development in recent decades, particularly with advances in analytical and computer sciences, and various therapeutic areas and measurement tools,[42] but only recently have fundamentals began to be discussed, perhaps in the last few years.[43] The authors argue that the knowledge requirements and the curriculum should evolve to reflect this, which is why the question was raised as a point for discussion.

The issue of funding of TDM tests is extremely important, although not related to the education aspect. We found that for some tests or cases patients pay directly, which may be a barrier to perform a TDM. The same concern and issue arise when pharma or assay companies pay for TDM due to their commercial interests.

The authors recognize that this study has several limitations. First, we selected only articles describing educational programmes on TDM. Despite the narrow inclusion criteria, a large volume of articles and websites were screened, and we consider we were as thorough as possible, which is why it is disappointing that this is what is currently available on the topic. The response rate could be increased but the fact is that most European countries are represented, as well as information from the United States, Japan, Australia and Argentina. We managed to obtain information for many continents, despite the fact that we selected only articles in English.

Secondly, the 30% questionnaire response rate risks selection bias, especially when responses from academia prevailed (68%). This might be due to the selection of responders from journals and the COST platform. Nevertheless, this could reflect the current situation of the discussion, which is purely academic for the time being. Conversely, further studies should be organized with clinical societies to evaluate the needs of TDM education and to develop educational programmes suited to a variety of professionals.

The primarily European geographical distribution of responses may introduce a regional bias. Information from Argentina, Japan and the United States highlights the similarity in educational approaches, and we consider that starting a discussion on the issue will further increase awareness among professional societies. Our results should be interpreted as an initial effort to spark a broader discussion on the development of TDM educational standards.

## 5 | CONCLUSIONS

TDM education is scattered across different subjects, disciplines and degrees. It is oriented more towards physicians and pharmacists, and less towards other health professionals, including biochemists. General guidelines are lacking and funding is mainly public. The emergence of new diseases and the development of new medicines may increase TDM need, thereby requiring continuous education and funding.

It is necessary to consider developing a comprehensive educational programme in TDM, tailored towards specific drugs and diseases, and incorporating the appropriate analytical and pharmacological methods.

## AUTHOR CONTRIBUTIONS

**Guenka Petrova:** Design; data collection; data interpretation; writing an initial draft; writing final version. **Stiliyana Blagova:** Data collection; data interpretation; writing an initial draft; writing final version. **Konstantin Tachkov:** Data collection; data interpretation; writing an initial draft; writing final version. **Marlene Santos:** Data collection; data interpretation; writing an initial draft; writing final version. **James Bluett:** Data collection; data interpretation; writing an initial draft; writing final version. **Merita Rumano:** Data collection; data interpretation; writing an initial draft; writing final version. **Elena Kkolou:** Data collection; data interpretation; writing an initial draft; writing final version. **Elena Drakalska:** Data collection; data interpretation; writing an initial draft; writing final version. **Marija Arev:** Data collection; data interpretation; writing an initial draft; writing final version. **Mehtap Cakmak Barsbay:** Data collection; data interpretation; writing an initial draft; writing final version. **Denis Mulleman:** Design; data elaboration; data interpretation; writing an initial draft; writing final version; project leader.

## ACKNOWLEDGEMENTS

This article is based on work from the European Cooperation in Science and Technology (COST) Action "European Network on Optimising Treatment with Therapeutic Antibodies in chronic inflammatory diseases (ENOTTA) CA 21147", supported by COST and the NIHR Manchester Biomedical Research Centre (NIHR203308). The authors thank all who participated in the questionnaire and provided their input in lightening the TDM education and practice.

## CONFLICT OF INTEREST STATEMENT

Authors declare no conflict of interest.

## DATA AVAILABILITY STATEMENT

There are no data sets created for this manuscript.

## ORCID

*Guenka Petrova* https://orcid.org/0000-0001-8116-5138
*Konstantin Tachkov* https://orcid.org/0000-0002-3961-7556
*Marlene Santos* https://orcid.org/0000-0001-5020-5942
*James Bluett* https://orcid.org/0000-0001-5062-5779
*Merita Rumano* https://orcid.org/0000-0003-3891-0918
*Elena Drakalska* https://orcid.org/0009-0005-0322-0935
*Marija Arev* https://orcid.org/0009-0007-8700-1637
*Mehtap Cakmak Barsbay* https://orcid.org/0000-0001-7609-6254
*Denis Mulleman* https://orcid.org/0000-0003-4089-7513

## REFERENCES

1. Reynold S, Park GD, Johnson GF, Vesell ES. Therapeutic drug monitoring. *Clin Pharmacol Ther*. 1988;43(4):345-353.
2. Birkett DJ. Pharmacokinetics made easy: therapeutic drug monitoring. *Aust Prescr*. 1997;20(1):9-11. doi:10.18773/austprescr.1997.005
3. Tange SM, Grey VL, Senecal PE. Therapeutic drug monitoring in pediatrics: a need for improvement. *J Clin Pharmacol*. 1994;34(3):200-214. doi:10.1002/j.1552-4604.1994.tb03987.x
4. Shenfield GM. Therapeutic drug monitoring beyond 2000. *Br J Clin Pharmacol*. 2001;52(Suppl 1):3S-4S. doi:10.1046/j.1365-2125.2001.0520s1003.x
5. Gross AS. Best practice in therapeutic drug monitoring. *Br J Clin Pharmacol*. 2001;52(Suppl 1):5S-10S. doi:10.1046/j.1365-2125.2001.0520s1005.x
6. Kang JS, Lee MH. Overview of therapeutic drug monitoring. *Korean J Intern Med*. 2009;24(1):1-10. doi:10.3904/kjim.2009.24.1.1
7. Holford N, Petric Z. The rational basis for personalized treatment using concentration-guided dosing. *Ther Drug Monit*. 2025:1-8. doi:10.1097/FTD.0000000000001350 Epub ahead of print
8. Thomson A. Why do therapeutic drug monitoring. *Pharm J*. 2004;273:153-155.
9. Streetman DS, Nafziger AN, Destache CJ, Bertino AS Jr. Individualized pharmacokinetic monitoring results in less aminoglycoside-associated nephrotoxicity and fewer associated costs. *Pharmacotherapy*. 2001;21(4):443-451. doi:10.1592/phco.21.5.443.34490
10. Darko W, Medicis JJ, Smith A, Guharoy R, Lehmann DE. Mississippi mud no more: cost-effectiveness of pharmacokinetic dosage adjustment of vancomycin to prevent nephrotoxicity. *Pharmacotherapy*. 2003;23(5):643-650. doi:10.1592/phco.23.5.643.32199
11. Whiting B, Kelman AW, Bryson SM, et al. Clinical pharmacokinetics: a comprehensive system for therapeutic drug monitoring and prescribing. *Br Med J (Clin Res ed)*. 1984;288(6416):541-545. doi:10.1136/bmj.288.6416.541
12. Atkinson AJ Jr, Nordstrom K. The challenge of in-hospital medication use: an opportunity for clinical pharmacology. *Clin Pharmacol Ther*. 1996;60(4):363-367. doi:10.1016/S0009-9236(96)90192-7
13. Ensom MH, Davis GA, Cropp CD, Ensom RJ. Clinical pharmacokinetics in the 21st century: does the evidence support definitive outcomes? *Clin Pharmacokinet*. 1998;34(4):265-279. doi:10.2165/00003088-199834040-00001
14. Aronson JK, Hardman M. ABC of monitoring drug therapy: measuring plasma drug concentrations. *BMJ*. 1992;305(6861):1078-1080. doi:10.1136/bmj.305.6861.1078
15. Skrede S, Bogavac-Stanojević N, Dreesen E, Nielsen E, Zaninotto M, Mulleman D. Therapeutic drug monitoring of monoclonal antibodies in chronic inflammatory diseases: a snapshot of laboratories and applications across Europe. *Basic Clin Pharmacol Toxicol*. 2024;134(4):556-560. doi:10.1111/bcpt.13983
16. Reynolds DJ, Aronson JK. ABC of monitoring drug therapy: making the most of plasma drug concentration measurements. *BMJ*. 1993;306(6869):48-51. doi:10.1136/bmj.306.6869.48
17. Usman M, Rasheed H. Pharmacometrics and its Application in Clinical Practice, Editor(s): Zaheer-Ud-Din Babar. In: *Encyclopedia of pharmacy practice and clinical pharmacy*. Elsevier; 2019:227-238, ISBN 9780128127360. doi:10.1016/B978-0-12-812735-3.00132-1
18. Singh J. International conference on harmonization of technical requirements for registration of pharmaceuticals for human use. *J Pharmacol Pharmacother*. 2015;6(3):185-187. doi:10.4103/0976-500X.162004
19. Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ*. 2021;372:n71. doi:10.1136/bmj.n71
20. Bowers RD, Scott Asbill C. Traditional lecture versus case-based learning in a therapeutic drug monitoring course within an integrated pharmacy curriculum. *Innov Pharm*. 2022;13(1):1).article 19-4. doi:10.24926/iip.v13i1.4035
21. Cairns KA, O'Brien DJW, Corallo CE, Guidone DM, Dooley MJ. Pharmacist-led therapeutic drug monitoring: implementation of a successful credentialing model. *Pharm Pract*. 2017;47(6):477-482. doi:10.1002/jppr.1378
22. Samani K. Therapeutic drug monitoring: an e-learning resource. *Biosci Horizons*. 2009;2(2):113-124. doi:10.1093/biohorizons/hzp013

23. Firman P, Tan K-S, Clavarino A, Taing M-W, Whitfield K. Pharmacist-managed therapeutic drug monitoring programs within Australian hospital and health services—a national survey of current practice. *Pharmacy (Basel)*. 2022;10(5):135. doi:10.3390/pharmacy1005013
24. Ma E. Development and evaluation of a framework for a pharmacist therapeutic drug monitoring training program at St. Joseph's Healthcare Hamilton. Accessed May 27, 2025. https://utoronto.scholaris.ca/server/api/core/bitstreams/c50539f8-2b4a-4390-a3ab-aefb1b735f86/content
25. D'Angio RG, Stevenson JG, Lively BT, Morgan JE. Therapeutic drug monitoring: improved performance through educational intervention. *Ther Drug Monit*. 1990;12(2):173-181.
26. Heaton A, Nunes A. Clinical pharmacokinetics in the United States: the role of therapeutic drug monitoring. *Pharm Pract*. 2017;15(1):e654.
27. Bates DW, Soldin SJ, Rainey PM, Micelli JM. Strategies for physician education in therapeutic drug monitoring. *Clin Chem*. 1998;44(2):401-407. doi:10.1093/clinchem/44.2.401
28. Conselho do Colégio de Especialidade de Farmácia Hospitalar. Boas Práticas em Farmacocinética Clínica. 7.10.2021. Accessed June 17, 2025. https://www.ordemfarmaceuticos.pt/fotos/publicacoes/boas_praticas_farmacocinetica_clinica_11500176166c2cd4fcf3_1__131162354765d729a461222.pdf
29. Al-Saadi N. E-learning and its impact on future generations. *J Inf Technol Educ Res*. 2017;22(17):187-160.
30. EC. Council Recommendation of 16 June 2022 on a European approach to micro-credentials for lifelong learning and employability 2022/C 243/02. Accessed April 24, 2025. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32022H0627(02)
31. Monash University Handbook. *Graduate certificate on clinical pharmacy*. Accessed April 24, 2025. https://handbook.monash.edu/current/courses/P4004
32. University of Edinburg. Master of clinical pharmacy. Accessed April 25, 2025. https://www.ed.ac.uk/
33. Université Paris Descartes. Master of Medicines and Health Products Sciences - Path: Pharmacology and Pharmacochemistry. Available at: Master of Medicines and Health Products Sciences - Path: Pharmacology and Pharmacochemistry 12 months Postgraduate Program by Université Paris Cité|Top Universities. (Accessed 24 April 2025)
34. University of Tokio, Clinical Program of Master of Pharmacy. https://www.f.u-tokyo.ac.jp/en/
35. Pedersen L, Szecsi PB, Johansen PB, Bjerrum PJ. Evaluation of therapeutic drug monitoring in the clinical management of patients with rheumatic diseases: data from a retrospective single-center cohort study. *Biologics*. 2020;14:115-125. doi:10.2147/BTT.S262511
36. Nguyen NH, Solitano V, Vuyyuru SK, et al. Proactive therapeutic drug monitoring versus conventional management for inflammatory bowel diseases: a systematic review and meta-analysis. *Gastroenterology*. 2022;163(4):937-949.e2. doi:10.1053/j.gastro.2022.06.052
37. Amin A, Bourget P, Neven B, et al. Reiterated therapeutic drug monitoring (TDM) dosing to significantly improve the control of exposure to IV busulfan in infants and older children undergoing hematopoietic stem-cell transplantation (HSCT). *Blood*. 2015;126(23):4326. doi:10.1182/blood.V126.23.4326.4326
38. Koch BCP, Muller AE, Hunfeld NGM, et al. Therapeutic drug monitoring of antibiotics in critically ill patients: current practice and future perspectives with a focus on clinical outcome. *Ther Drug Monit*. 2022;44(1):11-18. doi:10.1097/FTD.0000000000000942
39. Imamura CK. Therapeutic drug monitoring of monoclonal antibodies: applicability based on their pharmacokinetic properties. *Drug Metab Pharmacokinet*. 2019;34(1):14-18. doi:10.1016/j.dmpk.2018.11.003
40. Fang Z, Zhang H, Guo J, Guo J. Overview of therapeutic drug monitoring and clinical practice. *Talanta*. 2024;266, Part 1:124996. doi:10.1016/j.talanta.2023.124996
41. National Institute for Health and Care Excellence (NICE). Therapeutic Drug Monitoring and Clinical Guidelines for Various Drugs. 2018. https://www.nice.org.uk
42. Buclin T, Thoma Y, Widmer N, et al. The steps to therapeutic drug monitoring: a structured approach illustrated with imatinib. *Front Pharmacol*. 2020;11:177. doi:10.3389/fphar.2020.00177
43. Ali AS, Abdel-Rahman MS, Bazuhair MA. Therapeutic drug monitoring: fundamentals and optimization. *Drug Discovery*. 2023;17:e15dd1015.


**How to cite this article:** Petrova G, Blagova S, Tachkov K, et al. Therapeutic drug monitoring education: The current state. *Br J Clin Pharmacol*. 2026;92(1):198-209. doi:10.1002/bcp.70252

## APPENDIX 1: Questionnaire

By selecting "Yes" in the next question, you agreed to participate in the study.

a. Yes
b. No

Thank you for your time and contribution.

1. Which best describes your principal affiliation?
   a. Academia
   b. Physician
   c. Pharmacist
   d. Regulator
   e. Other (please describe)
2. If you describe yourself as a physician, what is your specialty?

3. Name of your country _____
4. Is TDM part of the educational programme of health professionals in your country?
   a. Yes
   b. No
5. If you answered "Yes", at what level is the education organized?
   a. Undergraduate
   b. Postgraduate
   c. Both
6. How many academic hours are devoted to education on TDM?
   a. Less than one semester
   b. One semester
   c. More than one semester
   d. I do not know.
7. Do you have a programme in your country providing a degree in TDM?
   a. Bachelor's degree
   b. Master's degree

c. I do not know.

8. If you are aware of a degree (Bachelor or Master) with TDM education, can you please identify the degree and the university where it is taught? _____
9. According to your knowledge what kind of professionals are educated for TDM? (more than one answer is possible)
   a. Physicians during undergraduate education
   b. Practicing clinicians during post graduate education
   c. Pharmacist during undergraduate education
   d. Practicing pharmacists during post graduate education
   e. Biochemists
   f. Other (please describe)
   g. I do not know
10. For what kind of diseases is TDM usually performed (more than one answer is possible)
   a. Infectious
   b. Neurological
   c. Rheumatological
   d. Gastroenterological
   e. Psychiatric
   f. Antiarrhythmic
   g. Oncological
   h. Haematological
   i. Other (please specify)
11. For what kind of medicines is TDM a common practice in your country (more than one answer is possible)
   a. Antibiotics
   b. Monoclonal antibodies
   c. Psychotropic
   d. Oncological
   e. Cardiovascular
   f. Anticoagulant
   g. For testing antidrug antibodies
   h. Other (please specify)
12. Is there a national regulation or recommendation that standardizes TDM practices in your country?
   a. Yes
   b. No
13. If you answered "Yes", please provide the name or reference of the regulation or recommendations.

14. If you do not have a regulation or recommendations, which standard is used by healthcare professionals? _____
15. If available in your country, who is paying for TDM?
   a. Patient
   b. Hospital
   c. Compulsory health insurance fund
   d. Voluntary (private) health insurance fund
   e. Companies (producing medicines)
   f. Companies (producing tests or kits)
   g. Other

_____

_____

Thank you for your participation. Would you like to be interviewed in more detail regarding TDM in your country?