SYSTEMATIC REVIEW AND META-ANALYSIS

Do final-year medical students have sufficient prescribing competencies? A systematic literature review

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AIMS

Prescribing errors are an important cause of patient safety incidents and are frequently caused by junior doctors. This might be because the prescribing competence of final-year medical students is poor as a result of inadequate clinical pharmacology and therapeutic (CPT) education. We reviewed the literature to investigate which prescribing competencies medical students should have acquired in order to prescribe safely and effectively, and whether these have been attained by the time they graduate.

METHODS

PubMed, EMBASE and ERIC databases were searched from the earliest dates up to and including January 2017, using the terms 'prescribing', 'competence' and 'medical students' in combination. Articles describing or evaluating essential prescribing competencies of final-year medical students were included.

RESULTS

Twenty-five articles describing, and 47 articles evaluating, the prescribing competencies of final-year students were included. Although there seems to be some agreement, we found no clear consensus among CPT teachers on which prescribing competencies medical students should have when they graduate. Studies showed that students had a general lack of preparedness, self-confidence, knowledge and skills, specifically regarding general and antimicrobial prescribing and pharmacovigilance. However, the results should be interpreted with caution, given the heterogeneity and methodological weaknesses of the included studies.

CONCLUSIONS

There is considerable evidence that final-year students have insufficient competencies to prescribe safely and effectively, although there is a need for a greater consensus among CPT teachers on the required competencies. Changes in undergraduate CPT education are urgently required in order to improve the prescribing of future doctors.

WHAT IS ALREADY KNOWN ABOUT THIS SUBJECT
- Prescribing errors can result in patient harm and high healthcare costs.
- Junior doctors write many prescriptions in hospitals but one in 10 of their prescriptions may contain errors, in part because of poor prescribing competencies.
- It is not clear whether medical students lack essential prescribing skills and competencies when they graduate.

WHAT THIS STUDY ADDS
- There is a need for a greater consensus among clinical pharmacology and therapeutics teachers on the competencies that medical students should have in order to prescribe safely and effectively.
- Despite the lack of a consensus, there is considerable evidence that final-year medical students have not attained sufficient competencies for safe and effective prescribing as medical doctors, especially regarding general and antimicrobial prescribing and pharmacovigilance.
- Changes in clinical pharmacology and therapeutics education during the undergraduate medical curriculum are urgently required, in order to improve the prescribing competencies of future doctors.

Introduction

Rational prescribing (i.e. effectively, safely and at low cost) is a challenging task for every medical doctor as it involves a mixture of knowledge, skills and attitudes integrated into the complex social context of the clinical workplace [1]. Poor prescribing may result in prescribing errors and adverse drugs reactions, which could adversely affect patient outcomes, leading to hospitalization or even death [2, 3]. There is considerable evidence that junior hospital doctors in the first 2 years of practice after graduation make relatively many prescribing errors (8–10% of prescriptions) and are more likely to make these errors than consultants [4–6]. This is particularly worrying as junior doctors write a large proportion (68%) of hospital prescriptions [5].

Studies have identified a range of factors underlying the poor prescribing skills of junior doctors, including individual (e.g. lack of experience), environmental (e.g. high workload), organizational (e.g. lack of standardization) and patient (e.g. polypharmacy) factors [4, 7, 8]. A lack of prescribing competencies (i.e. knowledge, skills and attitudes) among junior doctors is frequently mentioned [7, 9], which might be due to inadequate undergraduate education and training in clinical pharmacology and therapeutics (CPT). Indeed, a recent study showed that European final-year medical students lacked essential prescribing competencies and felt that their medical curriculum had not adequately prepared them for safe prescribing [10]. Another recent study showed that CPT education across Europe is still mainly based on traditional learning methods (e.g. lectures and written examinations), which seem to be associated with a lower level of prescribing knowledge and skills among final-year students than problem-based learning methods (e.g. patient simulation and real-life prescribing) [11].

Although these findings are concerning, there is no comprehensive overview of the literature addressing the competencies that medical students should have acquired in order to prescribe safely and effectively as medical doctors, and whether these have been attained by the time they graduate. Previous literature reviews focused mainly on the prevalence and causes of prescribing errors made by junior doctors [12, 13]. By shifting the focus to final-year students rather than junior doctors, we aimed to identify possible shortcomings in undergraduate CPT education that could

be improved in the future. To this end, we conducted a systematic search of the peer-reviewed literature with the following two research questions: (i) which prescribing competencies should medical students have acquired in order to prescribe safely and effectively by the time they graduate?; and (ii) do final-year medical students have sufficient prescribing competencies?

Methods

Data sources and literature search strategy

We performed a systematic search to identify descriptive or observational studies of the prescribing competencies of final-year medical students. The review was conducted and performed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [14]. The study protocol was registered in the PROSPERO database (registration number CRD42017067063). With the assistance of a medical information specialist (R.O.), we searched the PubMed, Excerpta Medica Database (EMBASE) and Education Resources Information Center (ERIC) databases systematically from the earliest dates up to 10 January 2017. PubMed was used as the standard medical research database, and the EMBASE and ERIC databases were used to detect articles published in more education-orientated journals. For each database, the search terms used were variations of three key concepts: competence, prescribing and medical student. Full details of the search strategy in PubMed, EMBASE and ERIC are provided in Appendix S1. Duplicate articles were excluded and the remaining articles were screened for eligibility. Articles that were not available in digital form were retrieved from national university libraries or from the original author. The references of relevant articles were also screened using the forward and backward snowball method [15].

Study selection

First, two researchers (D.B. and S.G.) screened the titles and abstracts independently for eligibility. Disagreements were resolved by consensus with a third researcher (J.T.). Articles were included if they described prescribing competencies that medical graduates should have acquired or if they

evaluated prescribing competencies of final-year medical students. Prescribing competencies were defined as knowledge, skills or attitudes that are relevant to safe and effective prescribing. Final-year medical students were defined as students who would graduate from medical school within 1 year or who had recently graduated but had not yet started working as a junior doctor (i.e. medical graduates). The following exclusion criteria were used: (i) outcome measure not related to prescribing competencies; (ii) intervention studies (e.g. evaluation of a specific educational intervention or teaching method); (iii) not including final-year medical students (e.g. focusing only on lower-grade medical students, junior doctors); (iv) non-original research (i.e. reviews, editorials, letters to the editor, conference abstracts, symposium reports); (v) articles that only measure psychometric properties of assessments (e.g. validity,

reliability); (vi) languages other than English, German or Dutch; and (vii) abstract not available. Reasons for exclusion were documented (Figure 1). In cases of doubt, the full-text article was obtained and screened. Thereafter, the researchers screened the full-text articles for eligibility, using the same inclusion and exclusion criteria as above, with the additional exclusion criterion of full-text not available.

Data extraction and quality assessment

Data were extracted using the Best Evidence Medical Education (BEME) Collaboration coding sheet (Appendix S2) [16]. The BEME coding items used were administrative, context, stated aim of study and documented performance. The Kirkpatrick model of hierarchy of evaluation, modified by Freeth, was used to evaluate the outcome level (Table 2) [17, 18]. The
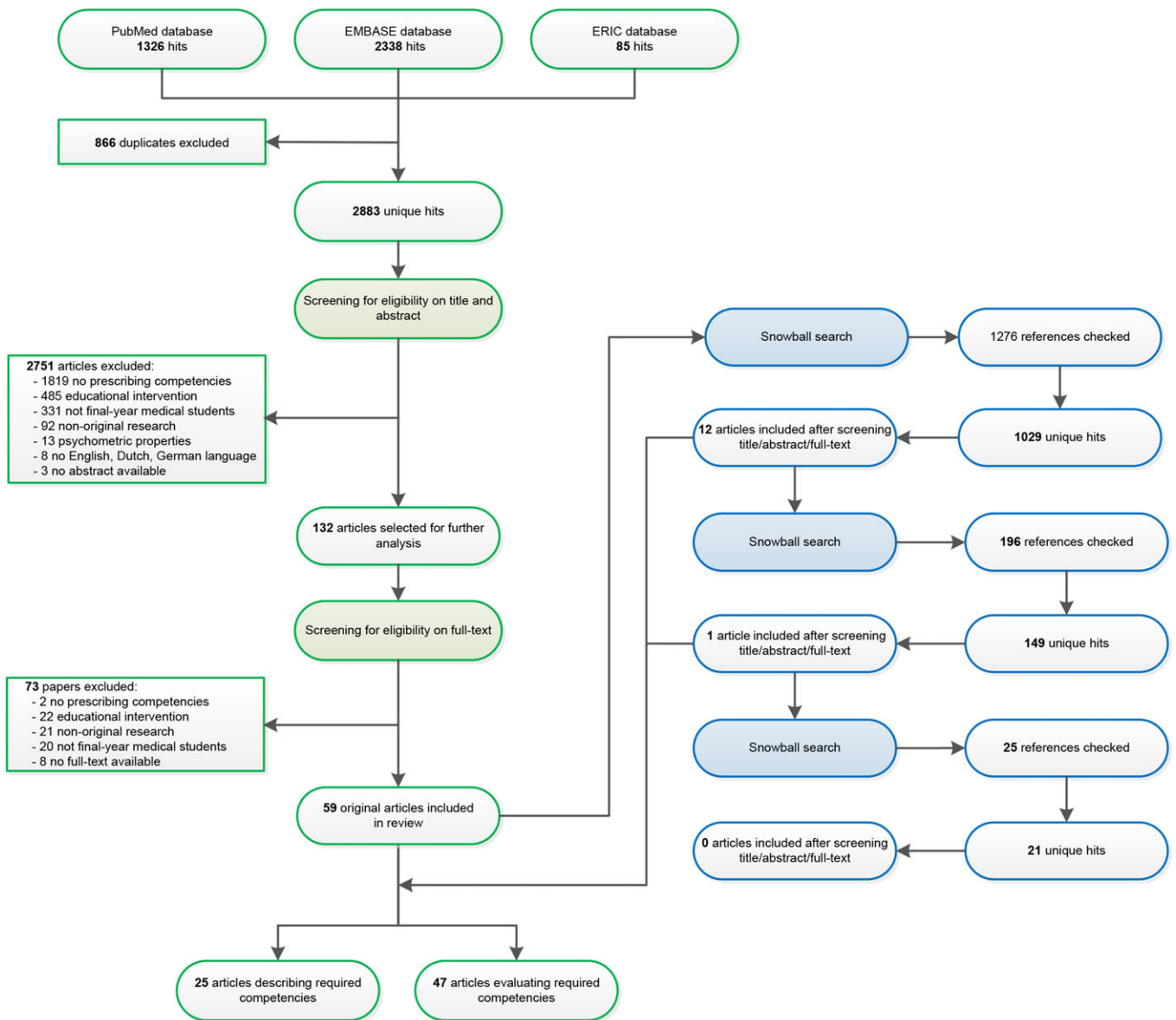
Figure 1
Flowchart of the systematic literature search

main CPT topics were identified and the methodological quality of articles evaluating prescribing competencies was assessed using the Medical Education Research Quality Instrument (MERSQI) [19]. It was not possible to use this instrument for articles describing competencies as almost all articles were based on expert opinion and did not provide quantitative data. The MERSQI instrument consists of six domains: study design, sampling, type of data, validation of evaluation instrument, data analysis and outcomes measured. The maximum score for each domain was 3, producing a maximum possible score of 18 and a potential range of 5–18. Although there is no defined cut-off for high- or low-quality study methods, a previous study used a MERSQI score of 14 or higher as a cut-off for high quality [20]. Two researchers (D.B. and S.G.) extracted data and assessed data quality independently, with a third author (J.T.) being involved, if necessary, to reach a consensus.

Data analysis

All descriptive analyses were performed in IBM SPSS version 22.0 (Chicago, IL). The total mean MERSQI score (accounting for 'non-applicable' responses) was calculated. Moreover, the proportion of articles published in different years, on different continents and involving different health professions was calculated. Given the variety of study designs and outcomes studied, no quantitative analysis or additional analysis of risk for bias was performed.

Results

Search results

The initial search identified 3749 articles. The flowchart of the search, selection and review process is presented in Figure 1. Eleven articles could not be obtained from either the library or the corresponding authors, and were thus excluded. In total, 59 articles met the inclusion criteria; the 1276 references from these articles were snowball-searched, which yielded 13 new articles. In total, 72 articles were included in the qualitative analysis, of which 25 described (Table 1) and 47 evaluated (Table 2) the competencies of final-year medical students.

Study characteristics

The number of articles evaluating prescribing competencies was found to have increased in the past two decades, from two articles in 2000 to eight in 2016; a similar trend was not seen for articles describing competencies (Figure 2). Of the 25 articles describing competencies, 12 came from Europe, 10 from North America, two from Asia and one from Australia. In terms of CPT topics, most articles (72%) described competencies in general prescribing. The vast majority of articles (96%) were based on expert opinion; only one used a cross-sectional design.

Of the 47 articles evaluating competencies, 22 were from Asia, 12 from Europe, seven from North America, four from Africa and two from Australia. In terms of CPT topics, most articles (32%) evaluated competencies in antimicrobial prescribing and resistance, and in general prescribing (26%).

Most studies (85%) used a cross-sectional survey as the primary evaluation method; other evaluation methods comprised clinical cases (n = 3) [10, 21, 22], clinical vignettes (n = 3) [23–25], multiple-choice exams (n = 2) [10, 26], therapeutic consultations with patients in general practice (n = 1) [27], drug prescriptions during internship (n = 1) [28] and a mixture of quantitative and qualitative methods (n = 1) [29]. In total, 10 339 final-year medical students were involved. The median number of students per study was 104 (range 1–2413). Besides final-year medical students, some studies also involved 1–5th year students (n = 20) [24–26, 28, 30–45], junior doctors and residents (n = 8) [25, 28, 33, 46–50], medical specialists (n = 2) [48, 50], pharmacy students (n = 3) [32, 51, 52], dental students (n = 2) [31, 41] and nonhealthcare students (n = 1) [40].

Study quality

Of the 25 articles describing competencies, four articles (16%) were based on the opinion of experts from one institution, 16 (64%) on the opinion of experts from multiple institutions within one country (four used the Delphi method) and four (16%) on the opinion of experts from multiple countries (one used the Delphi method). Only four Delphi studies described how a consensus among experts was achieved [53–56].

Of the 47 articles evaluating competencies, 27 (57%) had a single-institution design, 45 (96%) reported objectively measured outcomes, and 21 (45%) had a response rate <50% or did not report it. Thirty-two articles (68%) did not discuss the validity and reliability of the evaluation method used. Almost all articles (92%) used appropriate data analysis; however, only 30 (64%) used analytical methods other than descriptive analysis. The total MERSQI scores for the articles ranged from 6.5 to 13.5, with a mean (standard deviation) of 10.5 (1.6). Four (9%) articles measured students' perceptions or attitudes as the primary outcome (Kirkpatrick levels 1 and 2a), 41 (87%) measured students' knowledge or skills (Kirkpatrick level 2b), and two (4%) measured students' behaviour (Kirkpatrick level 3).

Which prescribing competencies should medical students have acquired by the time they graduate?

Regarding general prescribing, Sice was the first to define 13 competencies for undergraduate pharmacological education based on his own experience [57]. In 1990, Nierenberg developed a more detailed list of 17 knowledge, 16 skills, and five attitude items relevant for general prescribing, based on a consensus among CPT teachers in the USA [58]. Walley and Webb developed an almost identical list of 16 knowledge, 14 skills and four attitude items based on a Delphi study among clinical pharmacologists in the UK and Ireland [59]. This Delphi study served as a basis for the 2003 British Pharmacological Society (BPS) core curriculum described by Maxwell and Walley [60], which includes 48 knowledge, 35 skills and 19 attitude items and which was largely taken over in an international paper by Birkett *et al.* [61]. In 2012, Ross and Maxwell updated the BPS curriculum to 226 knowledge and 58 skills items [62], based on another Delphi study among CPT teachers in the UK [55]. De Vries [63] and Lum *et al.*

Table 1

Identified articles (*n* = 25) describing the prescribing competencies of final-year medical students

Author	Country	Aim	CPT topic	Methods	Main results
Antman et al. (2016) [71]	USA	To define core competencies for the prevention and management of prescription drug misuse for medical education	Drug misuse	Evidence based on the opinion of a working group consisting of 4 deans and 2 leaders of medical societies in one country	10 core competencies for the prevention and management of prescription drug misuse
Baker et al. (2011) [75]	UK	To develop a core list of 100 commonly prescribed drugs to support prescribing education	General prescribing	Evidence-based retrospective analysis of prescribing data from primary and secondary care and a cross-sectional survey among 148 FY1 doctors	A core list of 100 commonly prescribed drugs that is useful for teaching prescribing
Banna et al. (1994) [100]	United Arab Emirates	To present a core curriculum for the teaching of pharmacology and therapeutics for medical students	General prescribing	Evidence based on the opinion of 4 CPT teachers from one institution	27 knowledge objectives and 21 skill objectives for pharmacology and therapeutics education
Borgeat et al. (1985) [72]	Canada	To describe specific learning objectives for the teaching therapeutic skills of a psychological nature to future physicians	Psychotherapy	Evidence based on the opinion of psychiatry teachers from one institution	3 cognitive, 14 aptitudinal, and 5 attitudinal objectives for teaching therapeutics skill of a psychological nature
Davenport et al. (2005) [67]	UK; BSAC	To define learning outcomes for prudent antimicrobial prescribing to undergraduate medical students	Antimicrobial prescribing and resistance	Evidence based on the opinion of 2 working groups consisting of teachers from multiple institutions in one country	12 learning objective domains for undergraduate education of prudent antibiotic prescribing
de Vries (1993) [63]	The Netherlands	To define a framework for the whole problem-solving prescribing process and the learning objectives for medical education that can be derived from it	General prescribing	Evidence based on the opinion of general practitioners and clinical pharmacologists from multiple institutions in one country	8 cognitive skills, 2 motor skills and 6 communication skills for CPT education
Donnenberg et al. (2016) [66]	USA; ACCP	To develop a comprehensive set of guidelines in clinical pharmacology for entering residency	General prescribing	Evidence based on the opinion of medical teachers from multiple institutions in one country	8 topics for clinical pharmacology education
Flockhart et al. (2002) [65]	USA	To design and evaluate a core curriculum in CPT for final-year medical students	General prescribing	Evidence based on a literature survey and the opinion of CPT teachers from 2 institutions in one country	13 learning objectives for a core curriculum in CPT
Gitanjali & Shashindran (2006) [101]	India; IPS	To develop a draft curriculum for clinical pharmacology for medical undergraduates	General prescribing	Evidence based on a modified Delphi study[a] among pharmacologists of multiple institutions in one country	13 knowledge, 3 psychomotor skills, 12 attitudes, and communication skills for clinical pharmacology education
Lum et al. (2013) [64]	Australia	To develop a set of national competencies for teaching safe and effective prescribing during the medical curriculum	General prescribing	Evidence based on the opinion of 3 teachers from 3 institutions in one country	12 core competencies for safe and effective prescribing education
Mathur (2004) [102]	India	To describe a pharmacology curriculum for medical students	General prescribing	Evidence based on the opinion of 1 pharmacologist from one institution	8 learning objectives for teaching pharmacology

(*continues*)

Table 1

(Continued)

Author	Country	Aim	CPT topic	Methods	Main results
Maxwell & Walley (2003) [60]	UK	To define national learning outcomes in CPT and to identify the minimum knowledge for medical graduates to prescribe safely and effectively	General prescribing	Evidence based on the opinion of 2 CPT teachers from 2 institutions in one country	48 core knowledge and understanding, 35 core skill, 19 core attitude learning outcomes for CPT education. 201 core drugs and 148 core diseases that students should know about
Midlöv et al. (2015) [53]	Sweden	To identify the core competencies in basic and clinical pharmacology for medical students	General prescribing	Evidence based on a modified three-round Delphi study involving 25 physicians of multiple institutions in one country	40 core competencies for basic and clinical pharmacology education
Murison et al. (2013) [69]	USA; AAPM	To define learning outcomes for a new pain medicine curriculum for medical students	Pain medicine	Evidence based on a literature survey among 15 pain physicians of multiple institutions in one country	27 recommended topics for pain medicine
Nierenberg (1990) [58]	USA; CMSECPT	To formulate an essential core curriculum for medical students in CPT	General prescribing	Evidence based on a consensus among 40 faculty members and council representatives of multiple institutions in one country	17 core knowledge, 16 core skill and 5 core attitude learning outcomes for CPT education
O'Brien et al. (2009) [73]	USA	To describe the development and implementation of a pharmacogenomics course for health professional students	Pharmacogenomics	Evidence based on the opinion of a group of medical and health science teachers from 2 institutions in one country	7 molecular knowledge, 8 pharmacology knowledge and 7 technical skill learning outcomes for pharmacogenomics education
Orme et al. (2002) [74]	EACPT	To develop a list of essential drugs and diseases for a core curriculum in CPT	General prescribing	Evidence based on the opinion of a working group of 9 CPT teachers from nine different European countries	A list of 120 drugs that students must know about, 47 drugs that students must be aware of; 67 diseases that students must know how to treat; 158 diseases that students must be able to diagnose; 36 diseases that students should be aware of
Birkett et al. (2010) [61]	IUPHAR	To present a model core curriculum for CPT and prescribing for medical students	General prescribing	Evidence based on the opinion of clinical pharmacologists from multiple countries	63 core knowledge and understanding, 39 core skill, 19 core attitude learning outcomes for CPT and prescribing education
Pulcini & Gyssens (2013) [68]	France and the Netherlands	To review the education of prescribers of antibiotics, and analyse and discuss all relevant aspects	Antimicrobial prescribing and resistance	Evidence based on the opinion of 2 infectiologists from 2 countries	34 learning objectives outcomes for prudent antibiotic prescribing, divided among 10 topics
Ross & Loke (2010) [55]	UK; BPS	To create a consensus on the required competencies for new graduates in the area of prescribing	General prescribing	Evidence based on a systematic review and modified two-round Delphi study involving 21 experts in clinical pharmacology, pharmacy and medical education from multiple institutions in one country	50 learning outcomes for prescribing education
Ross & Maxwell (2012) [62]	UK; BPS	To provide a clear statement of the learning outcomes in clinical pharmacology and prescribing, and to describe a curriculum that might enable medical students to achieve these outcomes	General prescribing	Evidence based on a previous Delphi study and opinion of 2 CPT teachers from 2 institutions in one country	226 core knowledge and understanding and 58 core skill learning outcomes for teaching clinical pharmacology and prescribing. 98 drug classes and 125 therapeutic problems that students should be familiar with
Sice (1975) [57]	USA	To define the basic objectives for pharmacological education for preclinical students, clerks and residents	General prescribing	Evidence based on the opinion of 1 pharmacologist from 1 institution	6 learning objectives for pharmacological education for preclinical medical students, 7 objectives for clerks and 5 objectives for residents

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Table 1
(Continued)

Author	Country	Aim	CPT topic	Methods	Main results
Taylor et al. (2016) [70]	Barbados	To create a summative document containing aims, objectives and methods that can be used for the training of healthcare professionals in ward-based inpatient diabetes care	Diabetes care	Evidence based on the opinion of 55 final-year medical students of 1 institution using a four-stage approach	13 aims, 29 learning objectives and 21 methods for the inpatient diabetes care
Turner & Weiner (2002) [56]	USA	To develop expert-based guidelines for a medical curriculum on chronic pain evaluation and management in older adults	Pain medicine	Evidence based on a modified two-round Delphi study involving 12 experts in pain management and medical education of multiple institutions in one country	8 pain assessment knowledge, 7 pain management knowledge, 12 skills/abilities and 12 attitude items for chronic pain curriculum
Walley & Webb (1997) [54]	UK; BPS	To develop a national core curriculum in CPT for medical education	General prescribing	Evidence based on a four-round Delphi study involving 8 senior clinical pharmacologists from 2 countries	16 core knowledge and understanding, 14 core skill and 4 core attitude learning outcomes for teaching CPT

AAPM, American Association of Physicists in Medicine; ACCP, American College of Clinical Pharmacy; BPS, British Pharmacological Society; BSAC, British Society for Antimicrobial Chemotherapy; CMSECPT, Council for Medical Student Education in Clinical Pharmacology and Therapeutics; CPT, clinical pharmacology and therapeutics; EACPT, European Association of Clinical Pharmacology and Therapeutics; FY1, foundation year 1; IPS, Indian Pharmacological Society; IUPHAR, International Union of Basic and Clinical Pharmacology
[a]No reference or description of the Delhi process was provided

[64] described specific competencies related to the process of rational prescribing. Flockhart et al. [65] and Donnenberg et al. [66] used the principles formulated by Nierenberg to develop learning outcomes for a core CPT curriculum in the USA. More recently, Midlöv et al. defined 40 prescribing competencies based on a Delphi study among physicians in Sweden [53]. Competencies mentioned in more than one study are listed in Appendix S3.

Besides general prescribing, Davenport et al. defined 12 competencies for prudent antimicrobial prescribing, based on a consensus between two UK working groups [67]. This study served as a basis for the 34 learning outcomes for antimicrobial stewardship defined by Pulcini and Gyssens [68]. Turner and Weiner used a Delphi study among pain specialists to develop 39 competencies for a chronic pain curriculum [56]. Murinson et al. defined 27 learning objectives for general pain medicine, based on a survey among pain specialists [69]. Other areas for which specific prescribing competencies have been described are diabetes care ($n = 1$) [70], drug misuse ($n = 1$) [71], psychotherapy ($n = 1$) [72] and pharmacogenomics ($n = 1$) [73].

Core drug lists
In 2002, Orme et al. was the first to describe a list of 120 'core drugs' that students should know in detail, and 47 drugs that students should be familiar with but not required to know in any detail [74]. Additionally, they provided a list of 67 'core diseases' that students should know how to treat, 158 diseases that students should be able to diagnose and 36 diseases of which students should be aware. One year later, Maxwell and Walley described a more extensive list of 201 core drugs about which students should have an understanding of the mechanism of action, appropriate indications, appropriate routes of administration, and important contraindications and side effects [60]. In addition, they reported 148 core diseases for which these drugs should be used. This list was further refined by Ross and Maxwell into 98 drug classes and 125 therapeutic problems that students should be familiar with [62]. More recently, Baker et al. developed a validated list of 100 commonly prescribed drugs for use when teaching prescribing, based on a retrospective analysis of prescribing data from primary and secondary care combined with a survey among 148 foundation year 1 doctors [75].

Do final-year medical students have sufficient prescribing competencies?
Fifteen articles evaluated students' attitudes to, and knowledge of, appropriate antimicrobial prescribing and resistance [23, 24, 35–37, 39, 40, 44, 48, 49, 52, 76–79]. Students generally had positive attitudes and perceptions about antimicrobial overuse and resistance [35, 49, 76, 77]. However, they had poor knowledge of the local prevalence of resistant bacteria [35, 49, 77, 79] and of the treatment and prevention of common infections [24, 49, 78, 79]. Additionally, they lacked self-reported confidence in choosing the correct antibiotic, deciding when to use combination therapy, and choosing the correct dose and interval of administration [35, 36, 77]. Only four studies reported a moderate-to-high level of knowledge about appropriate antimicrobial use among students [37, 40, 44, 52], and two described a moderate-to-high level

Table 2

Articles (n = 47) evaluating the prescribing competencies of final-year medical students

Author	Setting	Study design	Participants	CPT topic	Methods	Main results	Kirkpatrick level[c]	MERSQI-score[a]
Abbo et al. (2013) [23]	USA; 3 medical schools	Single-group, cross-sectional descriptive	317 final-year (4th) medical students	Antimicrobial prescribing and resistance	24-point self-administered electronic survey instrument about perceptions, knowledge and attitudes to antimicrobial use and resistance, including 11 clinical vignettes	92% agreed that knowledge of antimicrobials is important. Mean correct knowledge score was low (51%; max. 100%). Only one-third perceived their preparedness to be adequate in some fundamental principles of antimicrobial use. 90% wanted more education on appropriate use of antimicrobials	1, 2b	12
Abubakar et al. (2015) [30]	Malaysia: one medical school	Multiple groups, cross-sectional descriptive	37 penultimate-(4th) year and 50 final-year (5th) medical students	Pharmacovigilance	25-point self-administered written questionnaire about knowledge, attitudes and practices regarding ADRs and pharmacovigilance	78% agreed that ADR reporting is a professional obligation. 59% recognized the right functions of pharmacovigilance. Only 21% knew the method used to report ADRs; 47% had never received any training in how to report ADRs	1, 2b	11
Agrawal et al. (2013) [31]	India; one university	Multiple groups, cross-sectional descriptive	102 2nd-year and 98 final-year (5th) medical and dental students	Contraception	55-point self-administered written questionnaire about knowledge, attitudes, and barriers to practice regarding oral contraceptive pills	Average knowledge score was low (16.7; max. 30); final-year students had higher knowledge scores compared with 2nd year students. Most students had negative perceptions and attitudes to oral conceptive pills	2b	8.5
Al-Wadaani (2013) [87]	Saudi Arabia; one medical school	Single-group, cross-sectional descriptive	73 final-year (6th) medical students	Cardiovascular	22-point self-administered written questionnaire about knowledge, attitudes and practices regarding diabetes and diabetic retinopathy	Overall knowledge, attitude and practice scores were moderate (64.8; max. 100). Students lacked knowledge about the follow-up of diabetic patients for the screening of diabetic retinopathy. 90% of students did not know the proper angle of insulin injection	2b	10.5
Awad et al. (2012) [32]	Kuwait; one university	Multiple groups, cross-sectional descriptive	54 junior and 68 senior (4th–7th-year) medical and pharmacy students	Complementary and alternative medicines	Self-administered written questionnaire about knowledge, perceived effectiveness and barriers to complementary and alternative medicine	Medical students had poor knowledge of complementary and alternative medicine. Over two-thirds had positive attitudes. Lack of trained professionals and lack of scientific evidence were the most common perceived barriers	2b	9
Azeem et al. (2010) [80]	Pakistan; one university hospital	Single-group, cross-sectional descriptive	105 medical graduates	General prescribing	Self-administered written questionnaire about perceptions regarding preparation and competency to prescribe as junior doctors	19% considered themselves competent to prescribe at the time of graduation. <35% felt comfortable in providing information about treatment options to patients. The majority (59–95%) indicated a lack of formal teaching and practice at skills relating to drug therapy	1, 2a	6.5

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Table 2

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Author	Setting	Study design	Participants	CPT topic	Methods	Main results	Kirkpatrick level[c]	MERSQI-score[a]
Beyhun et al. (2016) [85]	Turkey; one medical school	Single-group, cross-sectional descriptive	148 final-year (6th) medical students	Narcotics	Self-administered written questionnaire about awareness of synthetic cannabinoids	Students' mean awareness score was moderate (4.7; max. 9). Students lacked awareness of usage, illegal status and clinical effects of synthetic cannabinoids	2b	8.5
Brinkman et al. (2017) [10]	Europe; 17 medical schools from 15 countries	Single-group, cross-sectional descriptive	895 final-year (5th–6th) medical students	General prescribing	Online assessment of prescribing knowledge (24 MCQs) and skills (5 patient cases). Self-administered questionnaire about self-reported confidence, perceived preparedness for prescribing, and received CPT education	Overall knowledge score was moderate (70%, max. 100%). 46% of the therapies were inappropriate and 55% of the prescriptions contained an error. Students lacked confidence in essential prescribing skills and felt not adequately prepared for prescribing responsibilities. >60% were not satisfied with the quantity and quality of undergraduate CPT education	1, 2b	13.5
Brinkman et al. (2014) [27]	The Netherlands; one medical school	Single-group, cross-sectional descriptive	483 final-year (6th) medical students	General prescribing	Prescribing performance during 4 therapeutic consultations with real patients during clinical clerkship, self-administered online questionnaire on self-reported confidence in prescribing	Adequate performance score (7.93; max. 10). Majority (66–88%) lacked self-reported confidence in essential prescribing skills	2a, 3	9
Cheng & Yu (2012) [33]	China; one medical school	Multiple groups; cross-sectional descriptive	103 penultimate-year (6th) and 80 final-year (7th) medical students, 59 clinical master degree candidates, 50 clinical doctors	Narcotics	45-point self-administered written questionnaire about knowledge of cancer pain management	Senior medical students had a poor knowledge of cancer pain management, especially among non-oncological medical students	2b	11.5
Chuenchom et al. (2016) [76]	Thailand; three medical schools	Single-group; cross-sectional descriptive	455 final-year (6th) medical students	Antimicrobial prescribing and resistance	Self-administered written questionnaire about perception, attitude and knowledge of antimicrobial resistance, appropriate antimicrobial use and infection control	Mean knowledge scores were low (1.61; max. 5). Nearly all participants had a positive attitude about antimicrobial resistance. >10% reported that they had never learned about antimicrobial resistance and appropriate antibiotic use. Nearly all students wanted more education about rational antimicrobial use	1, 2b	10
Coombes et al. (2008) [81]	Australia; two teaching hospitals	Single-group; cross-sectional descriptive	101 final-year (4th) medical students	General prescribing	21-point self-administered written questionnaire about students' perceptions of their readiness to prescribe, associated risks and outcome if involved in an error, as well as their perceptions of available support	84% felt able to prescribe for simple complaints, whereas only 54% felt comfortable to prescribe warfarin and 66%to prescribe IV fluids. 99% were under the misapprehension that potentially harmful prescriptions would be safely administered. 79% perceived	2a	8.5

(continues)

Table 2
(Continued)

Author	Setting	Study design	Participants	CPT topic	Methods	Main results	Kirkpatrick level[c]	MERSQI-score[a]
						that they would be blamed if they made a prescribing error		
Dyar et al. (2013) [35]	France; one medical school	Multiple groups; cross-sectional descriptive	34 penultimate-year (5th) and 26 final-year (6th) medical students	Antimicrobial prescribing and resistance	41-point self-administered online questionnaire about knowledge, perceptions and beliefs about antibiotic resistance and prescribing	Final-year students were highly aware of and concerned about the overuse of antibiotics. Areas of non-confidence and gaps in knowledge were found. Students consistently overestimated the current burden of resistant bacteria and were unaware of success in reducing MRSA infections. 79% wanted more training in antibiotic selection	1, 2b	9.5
Dyar et al. (2014) [77]	Europe; seven medical schools from seven countries	Single-group; cross-sectional descriptive	338 final-year (5th–6th) medical students	Antimicrobial prescribing and resistance	41-point self-administered online questionnaire about knowledge, perceptions and beliefs about antibiotic resistance and prescribing	Students lacked confidence in combination therapy and dose selection of antibiotics. Students consistently overestimated the current burden of resistant bacteria and were unaware of success in reducing MRSA infections. 74% wanted more training in antibiotic selection	1, 2b	10.5
Dyasanoor & Urooge (2016) [28]	India; one university hospital	Multiple groups; cross-sectional descriptive	52 undergraduates, 221 interns[a], 227 postgraduates	General prescribing	Quality of 500 prescriptions dispensed by participants analysed according to 19 parameters	39% of the prescriptions by interns were not adequate because important parameters were missing. Prescriptions written by undergraduates were better than those written by interns and postgraduates	3	10
Grossman & Sheidler (1985) [25]	USA; one university hospital	Multiple groups; pretest intervention	4 2nd-year, 12 penultimate-year (3rd), 1 final-year (4th) medical student, 68 house officers	Narcotics	3 clinical vignettes about converting narcotic analgesic regimen in patients with pain	2% of the answers of medical students were within the correct range. There were no significant differences between the responses among individuals at different education levels	2b	10
Gyawali et al. (2016) [46]	Nepal; one university hospital	Multiple groups; cross-sectional descriptive	120 final-year (5th) medical students, 117 interns[a]	Generic prescribing and substitution	Self-administered written questionnaire about knowledge and perceptions of generic medicine and generic prescribing	Only 5% knew the correct regulatory limits for bioequivalence. 46% had the impression that brand-name medicines were required to meet higher safety standards than were generic medicines. 17% had the impression that generic medicines caused more side effects and were less effective than brand-name medicines	2b	12.5
Haque et al. (2016) [36]	Malaysia; one medical school	Multiple groups; cross-	41 3rd-year, 55 penultimate-year (4th) and 45 final-year (5th) medical students	Antimicrobial prescribing and resistance	21-point self-administered written questionnaire about knowledge, beliefs and practices regarding antibiotic resistance and prescribing	>50% of final-year students lacked confidence in combination therapy and dose and duration selection of antibiotics. Students consistently	1, 2b	12.5

(continues)

Table 2

(Continued)

Author	Setting	Study design	Participants	CPT topic	Methods	Main results	Kirkpatrick level[c]	MERSQI-score[a]
		sectional descriptive				overestimated the current burden of resistant bacteria. 88% wanted more training in rational antibiotic selection		
Harakeh et al. (2015) [37]	Saudi Arabia; two medical schools	Multiple groups; cross-sectional descriptive	1042 1st-year to final-year (6th) medical students	Antimicrobial prescribing and resistance	20-point self-administered written questionnaire about knowledge, attitudes and practices regarding the use of antibiotics for upper respiratory tract infections	93% of the final-year medical students had adequate knowledge of antibiotic effectiveness. Similarly, most were aware of antibiotic abuse and development of drug resistance in bacteria	2b	9.5
Hassali et al. (2007) [51]	Australia; 10 universities	Multiple groups; cross-sectional descriptive	400 final-year (5th) medical students and 289 final-year (5th) pharmacy pre-registrants	Generic prescribing and substitution	20-point self-administered online questionnaire about knowledge and perceptions of generic medicine, generic prescribing and generic substitution	Both groups scored poorly on the allowable bioequivalence limits, with pharmacy pre-registrants scoring better. Both groups incorrectly believed that generic medicines met lower safety standards, were inferior in quality, less effective and produced more side effects than brand-name medicines	2b	11.5
Heaton et al. (2008) [82]	UK; 25 medical schools	Multiple groups; cross-sectional descriptive	2413 medical students graduating in 2006–2008	General prescribing	17-point self-administered online questionnaire about undergraduate training and assessment in pharmacology and therapeutics, the acquisition of prescribing skills and self-reported confidence in prescribing	Only 38% felt confident about prescription writing and 35% had filled in a hospital prescription chart more than three times during training. 74% felt that there was (far) too little teaching and 56% disagreed that their assessment thoroughly tested knowledge and skills	1, 2a	10
Hema et al. (2012) [47]	India; one university hospital	Multiple groups; cross-sectional descriptive	80 final-year (5th) medical students, 88 interns[b] and 132 postgraduates	Pharmacovigilance	25-point self-administered written questionnaire about awareness, knowledge and methods to apply pharmacovigilance	Compared with interns and postgraduates, final-year students had a lower awareness score (2.5; max. 5), lower knowledge score (2.3; max. 8) and lower method of application score (5.8; max. 12)	2b	10
Holstein et al. (2000) [38]	Germany; 21 academic teaching and university hospitals	Single-group; cross-sectional descriptive	310 final-year (6th) medical students	Cardiovascular	20-point self-administered written questionnaire about clinically relevant diabetes treatment knowledge and experience	Marked gaps in manual experience and clinically relevant knowledge of diabetes, particularly in practical aspects of diabetes therapy. 45% had never injected insulin and 68% had no experience with the insulin pen. 81% were not satisfied with the diabetes teaching	1, 2b	10.5
Hoque et al. (2016) [39]	Bangladesh; one medical school	Multiple groups; cross-sectional descriptive	40 3rd-year, 33 penultimate-year (4th) and 34 final-year (5th) medical students	Antimicrobial prescribing and resistance	21-point self-administered written questionnaire about knowledge, attitudes and perceptions about antimicrobial resistance and rational use of antimicrobials	Participants had an average level of confidence in the rational use of antimicrobials, with final-year students being more confident than earlier-year students. Students underestimated the prevalence rate of MRSA infection. 94%	1, 2b	11.5

(*continues*)

Table 2

(Continued)

Author	Setting	Study design	Participants	CPT topic	Methods	Main results	Kirkpatrick level[c]	MERSQI-score[a]
						wanted more training in antibiotic selection		
Huang et al. (2013) [40]	China; three teaching hospitals	Multiple groups; cross-sectional descriptive	1236 medical students, including 241 final-year (5th year) students, 852 nonmedical students	Antimicrobial prescribing and resistance	30-point self-administered online questionnaire about knowledge, attitudes and perceptions about antibiotic use	Senior students had more knowledge of and positive attitudes to antibiotic use compared with junior students. No difference between penultimate-year (4th) and final-year (5th) students was observed. There was more excessive use of antibiotics among senior medical students	2b	12.5
Humphreys et al. (2006) [78]	Ireland; three medical schools	Single-group; cross-sectional descriptive	108 medical graduates	Antimicrobial prescribing and resistance	19-point self-administered written questionnaire about knowledge and understanding of treatment and prevention of common infections	±60% of the questions were answered correctly; questions regarding the rational use of antibiotics were poorly answered compared with other questions	2b	9
Ibia et al. (2005) [24]	USA; 21 medical schools	Multiple groups; cross-sectional descriptive	30 penultimate-year (3th) and 959 final-year (4th) medical students	Antimicrobial prescribing and resistance	Six paediatric vignettes regarding clinical management of different upper respiratory tract infections	99% were informed about the problems of antibiotic resistance. Majority of students 30–56%) prescribed antibiotics inappropriately for viral upper respiratory diseases. No subanalysis for done for study year	2b	11.5
Iffat et al. (2014) [41]	Pakistan; multiple universities	Multiple groups; cross-sectional descriptive	78 3rd-year, 212 penultimate-year (4th) and 241 final-year (5th) dental and medical students	Pharmacovigilance	31-point self-administered written questionnaire about knowledge, attitudes and perceptions about ADR reporting	88% had knowledge of ADRs. Medical students showed generally positive attitudes to ADR reporting. 55% did not know the definition of pharmacovigilance. Only 10% knew where to report ADRs. 72% indicated that they had not received any training in reporting ADRs	2b	12.5
Ismail et al. (2015) [83]	Malaysia; one medical school	Single-group; cross-sectional descriptive	23 final-year (5th) medical students	Pharmacovigilance	Self-administered written questionnaire about knowledge, attitudes and practice regarding ADRs and pharmacovigilance	96% knew the term ADRs. 57% did not know the method for reporting ADRs, although 78% had observed ADRs during clinical clerkships. 87% had not received any training in ADR reporting during their medical training	1, 2b	10
Jamshed et al. (2014) [52]	Malaysia; one medical school	Multiple groups; cross-sectional descriptive	72 final-year (5th) medical students and 51 final-year (5th) pharmacy students	Antimicrobial prescribing and resistance	Self-administered written questionnaire about understanding of antibiotic use and antibiotic resistance	94% showed adequate knowledge regarding the course content related to antibiotics. Only 30% were able to recognize penicillin and vancomycin-resistant bacteria. Pharmacy students had better knowledge than medical students	2b	11

(continues)

Table 2

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Author	Setting	Study design	Participants	CPT topic	Methods	Main results	Kirkpatrick level[c]	MERSQI-score[a]
Kaki (2011) [86]	Saudi Arabia; one medical school	Single-group; cross-sectional descriptive	325 final-year (6th) medical students	Narcotics	18-point self-administered written questionnaire about knowledge, beliefs and attitudes to cancer pain management	46% considered cancer pain as untreatable. 59% considered that the risk of addiction is high with opioid prescriptions. 68% limited opioid prescriptions to patients with poor prognosis. 63% indicated that they had received no education in pain medicine during their medical training	1, 2b	12
Khan et al. (2013) [42]	India; one medical school	Multiple groups; cross-sectional descriptive	148 3rd-year medical students and 130 medical graduates	General prescribing	Self-administered written questionnaire about knowledge, attitudes and behaviour regarding safe prescribing, including one patient case	The knowledge and attitudes of medical graduates were satisfactory. 12% prescribed unnecessary antibiotics. Prescribing skills were generally inadequate as errors in written prescriptions were commonly found	2b	10.5
Meher et al. (2015) [43]	India; one medical school	Single-group; cross-sectional descriptive	60 2nd-year, 60 penultimate-year (4th), 60 final-year (5th) medical students	Pharmacovigilance	21-point self-administered written questionnaire about knowledge, attitudes and practice of pharmacovigilance	Mean knowledge and attitude scores for final-year students were low (4.3; max. 7 and 1.7; max. 4, respectively). Penultimate-year students had better knowledge and attitude scores than final and 2nd-year students	2b	9.5
Olakunle et al. (2014) [79]	Nigeria; three medical schools	Single-group; cross-sectional descriptive	241 final-year (6th) medical students	Antimicrobial prescribing and resistance	Self-administered written questionnaire about knowledge of diagnosis and management of tuberculosis under DOTS	Only 46% correctly mentioned the various categories of the DOTS treatment regimen. 7% were able to identify the correct treatment duration for new tuberculosis	2b	10.5
Oshikoya et al. (2008) [21]	Nigeria; one medical school	Single-group; cross-sectional descriptive	34 final-year (6th) medical students	General prescribing	Self-administered written questionnaire about knowledge of principles of good prescribing and prescribing skills, including two clinical cases	92% knew that rational prescribing involved prescribing correct dosage of an appropriate medicine formulation. Less than 50% of the prescriptions included name, case file number, age and gender of the patient	2b	10.5
Ozoh et al. (2014) [89]	Nigeria; one medical school	Single-group; cross-sectional descriptive	139 final-year (6th) medical students	COPD	Self-administered written questionnaire about knowledge of COPD diagnosis and treatment	38% had good, 37% fair and 20% poor knowledge of COPD management. 55% were familiar with the GOLD guidelines. 28% correctly identified inhaled steroids and bronchodilators as therapy for stable COPD	2b	9.5
Puchner & Zacharisen (2002) [48]	USA; two academic and two teaching hospitals	Multiple groups; cross-sectional descriptive	36 medical students (junior/senior), 342 medical specialists	Antimicrobial prescribing and resistance	Self-administered written questionnaire about cephalosporin prescribing and knowledge of penicillin allergy	There was marked variation between study groups in the prescribing of cephalosporin and requesting penicillin skin testing. In general, medical specialists had a better knowledge of penicillin allergy than medical students	2b	8.5

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Table 2
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Author	Setting	Study design	Participants	CPT topic	Methods	Main results	Kirkpatrick level[c]	MERSQI-score[a]
Rehman et al. (2011) [88]	USA; one medical school and four teaching hospitals	Multiple groups; cross-sectional descriptive	121 final-year (4th) year medical students, 354 junior doctors	Cardiovascular	11-point self-administered written questionnaire about knowledge of hypertension diagnosis and management	Only 8% answered the questions regarding hypertension treatment correctly. Mean number of correct answers given by final-year students was low (5.2; max. 11), although they did better than junior doctors	2b	12.5
Rothwell et al. (2012) [29]	UK; three medical schools	Single-group; cross-sectional descriptive	65 medical graduates	General prescribing	Multiple methods, including face-to-face and telephone interviews, questionnaires and secondary data from prescribing safety assessment	73–80% of the graduates felt generally underprepared for prescribing. Only 16–19% of the graduates passed the prescribing safety assessment at the first attempt	2b	11
Scaioli et al. (2015) [44]	Italy; one medical school	Multiple groups; cross-sectional descriptive	465 1st year, 187 2nd-year, 190 3rd-year, 70 4th-year, 79 penultimate-year (5th), 59 final-year (6th) healthcare students	Antimicrobial prescribing and resistance	31-point self-administered written questionnaire about knowledge and attitude about antibiotic usage and antibiotic resistance	More than 90% answered all items correctly. However, 20% were not aware that antimicrobial drugs were not effective against viruses and that these drugs can cause secondary infections. However, no subanalysis by study year was performed	2b	11.5
Schutte et al. (2017) [45]	The Netherlands; eight medical schools	Multiple groups; cross-sectional descriptive	354 3rd-year, 92 4th-year, 106 penultimate-year (5th), 298 final-year (6th) medical students	Pharmacovigilance	10-point self-administered online questionnaire about pharmacovigilance awareness, skills and knowledge	Final-year students had marginally better knowledge scores than 3rd-year students (68% vs. 64%). Only 48% of the final-year students felt sufficiently prepared to report ADRs in future practice, and a substantial proportion did not know the authority to which they should report ADRs	1, 2b	12.5
Sharrad & Hassali (2011) [84]	Iraq; six medical schools	Single-group; cross-sectional descriptive	546 final-year (6th) medical students	Generic prescribing and substitution	23-point self-administered written questionnaire about perception and knowledge of generic medicines and generic prescribing	>70% of the respondents did not possess sufficient knowledge about bioequivalence limits for generic medicines. >60% of the students thought that generic medicines were inferior, less effective and produced more side effects than brand-name medicines	2b	13
Thriemer et al. (2013) [49]	Democratic Republic of Congo; one medical school and multiple hospitals	Multiple groups; cross-sectional descriptive	106 final-year (6th) medical students and 78 medical doctors	Antimicrobial prescribing and resistance	23-point self-administered written questionnaire about knowledge, attitudes and practices regarding antibiotic prescribing	Mean knowledge scores were generally low (4.9; max. 9) and did not differ significantly between the groups. Students had high self-confidence in antibiotic prescribing (86%), although this was lower than that of qualified doctors (95%)	2b	12.5

(continues)

Table 2

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Author	Setting	Study design	Participants	CPT topic	Methods	Main results	Kirkpatrick level[c]	MERSQI-score[a]
Upadhyaya et al. (2012) [22]	India; one teaching hospital	Single-group; cross-sectional descriptive	50 medical graduates	General prescribing	22-point self-administered written questionnaire about self-rated knowledge of the principles of good prescribing	48% rated their prescribing knowledge as average, and 18% as (very) poor. 58% felt that their medical training did not prepare them for rational prescribing. 42% felt that they had some problems with writing a prescription during their internship	1, 2a	7
Weber et al. (1986) [50]	Canada; one paediatric hospital	Multiple groups; cross-sectional descriptive	28 final-year (4th) medical students, 21 paediatric residents, 22 paediatricians	General prescribing	Six paediatric patient cases about knowledge of the price of frequently prescribed medications	Students' estimations were adequate in 40% of the cases, which was lower than that of paediatric residents (52%) and paediatricians (62%)	2b	8
Weinstein et al. (2000) [34]	USA; one medical school	Multiple groups; cross-sectional descriptive	88 1st-year medical students, 180 final-year (4th) medical students	Narcotics	49-point self-administered written questionnaire about knowledge and attitudes on pain and the use of opioid analgesics	Senior medical students scored as well as, or better than, 1st-year students on questions related to knowledge about pain. However, they had a more negative attitude to relieving chronic pain and seemed to have less understanding about the causes of pain in cancer patients	2b	10.5
Wheeler et al. (2004) [26]	UK; one medical school	Multiple groups; cross-sectional descriptive	87 2nd-year, 98 penultimate-year (3rd), 78 final-year (4th) medical students	General prescribing	Online multiple-choice examination about dose-calculating skills	The mean knowledge score for all students was low (1.2; max. 3), although final-year students had significantly better knowledge scores than 1st-year students	2b	9.5

ADR, adverse drug reactions; COPD, chronic obstructive pulmonary disease; CPT, clinical pharmacology and therapeutics; DOTS, directly observed treatment, short-course; GOLD, Global Initiative for Chronic Obstructive Lung Disease; IV, intravenous; MCQ, multiple choice question; MERSQI, Medical Education Research Quality Instrument; MRSA, methicillin-resistant *Staphylococcus aureus*

[a]The MERSQI has a minimum score of 5 and a maximum score of 18.

[b]Interns in India and Malaysia have graduated from medical school but receive their full registration as a medical doctor after completion of the internship

[c]Kirkpatrick's four levels of training evaluation are:

Level 1: Participation – covers learners' views on the learning experience, its organization, presentation, content, teaching methods and aspects of the instructional organization, materials and quality of instruction.

Level 2a: Modification of attitudes or perceptions – outcomes here relate to changes in the reciprocal attitudes or perceptions between participant groups towards intervention or simulation.

Level 2b: Modification of knowledge and skills – for knowledge, this relates to the acquisition of concepts, procedures and principles; for skills, this relates to the acquisition of thinking and problem solving, and psychomotor and social skills.

Level 3: Behavioural change – this documents the transfer of learning to the workplace or the willingness of learners to apply new knowledge and skills.

Level 4a: Change in organizational practice – this relates to wider changes in the organization or delivery of care, attributable to an educational programme.

Level 4b: Benefits to patients or clients – this relates to any improvement in the health or well-being of patients and clients as a direct result of an educational programme.
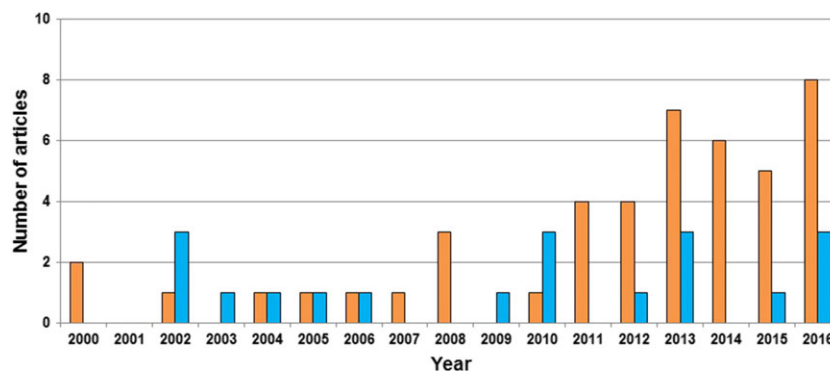
Figure 2

Identified articles describing prescribing competencies (■) and evaluating prescribing competencies (■) per year. Articles published before 2000 (*n* = 8) were not included

of self-reported confidence [39, 49]. Most students (74–98%) wanted more training in rational antibiotic selection during medical training [23, 35, 36, 39, 76, 77].

Eleven studies examined students' competencies regarding general prescribing [10, 21, 22, 26–28, 42, 50, 80–82]. Six studies, including a large study of 2413 UK students and graduates, reported that students felt that there was a lack of learning opportunities related to rational prescribing during their medical training, and that they felt underprepared for their prescribing responsibilities [10, 22, 29, 80–82]. Two studies, including a large multicentre study involving 895 European students, showed that students lacked essential prescribing knowledge and skills for common therapeutic problems [10, 21]. One study reported that students' knowledge and attitudes were satisfactory, although their prescribing skills for written patient cases were poor [42]. Other studies reported that prescribing skills, such as estimating drug costs [50] and drug calculation skills [26], were deficient. Only two studies investigated students' behaviour in clinical practice. Dyasanoor and Urooge reported that many drug prescriptions written by students during their last internship were erroneous because information about important entries was missing [28]. Conversely, Brinkman *et al.* showed that students were sufficiently skilled in conducting therapeutic consultations with real patients during the final internship of a context-learning CPT curriculum [27].

Six studies showed that students had a positive attitude to pharmacovigilance but lacked knowledge about where and how to report adverse drug reactions [30, 41, 43, 45, 47, 83]. Although many students (27–80%) had encountered an adverse drug reaction during clinical clerkships, very few (1–18%) had reported one [30, 43]. Three studies reported that students (72–94%) received no or little training in reporting adverse drug reactions during medical training [30, 41, 83].

Three studies showed that students generally had poor knowledge of, and negative perceptions about, prescribing generic medicines [46, 51, 84]. They were generally under the misapprehension that generic medicines were inferior in quality, less effective and produced more side effects than brand-name medicines [46, 51, 84]. They generally lacked knowledge of synthetic cannabinoids [85], cancer pain

management [33, 86] and conversion of narcotic analgesic regimens [25], although the latter study included only one final-year student. Moreover, senior students were more negative about relieving chronic pain and seemed to have less understanding than first-year students of the causes of pain in cancer patients [34].

Three studies investigated students' knowledge of the treatment of cardiovascular diseases [38, 87, 88]. Two studies reported deficiencies in students' knowledge of diabetes mellitus therapy – specifically, diabetic retinopathy and insulin treatment [38, 87]. Rehman *et al.* found that students lacked knowledge of the first-line treatment of uncomplicated arterial hypertension [88]. Awad *et al.* investigated students' knowledge of, and attitude to, alternative and complementary medicines [32]. Although students were positive about complementary and alternative therapies, their self-reported knowledge was poor. Agrawal *et al.* reported that while students had good-to-excellent knowledge of oral contraceptive pills, they lacked a positive attitude in practice [31]. Ozoh *et al.* found that students' general knowledge of chronic pulmonary obstructive disease treatment was modest, and that they were not familiar with international guidelines on optimal treatment [89].

Discussion

This was the first systematic review to investigate which prescribing competencies are required for safe and effective prescribing, and whether these have been attained by medical students by the time they graduate. We identified 25 studies that described a variety of prescribing competencies covering several CPT topics. The vast majority of these studies (72%) reported competencies regarding general prescribing and were based primarily on the early work of Nierenberg [58] and Walley and Webb [54]. Although there seems to be some agreement about specific competencies (e.g. taking drug history, writing prescriptions; Appendix S3), we found no clear consensus among CPT teachers on which prescribing competencies are required before medical students/graduates are allowed to prescribe. A clear definition of competencies is important to steer curricular content –

specifically, assessment – and students' approach to learning [90]. A lack of agreement on the required competencies of students has also been identified in other areas of medical education – for example, global health [91] and nutritional medicine [92]. It was not within the scope of the present review to determine why there is a lack of a consensus. One possibility is that most studies (64%) were focused on the local setting in a specific country – mainly the UK and USA. Authors might have chosen this local approach owing to structural differences in medical education between countries. Another possibility is that competencies were rarely the main focus of the retrieved articles, and thus provided little information on which to draw conclusions. Although studies were mainly based on expert opinion, few described how a consensus between experts was achieved. Additionally, most studies did not describe competencies in detail, which makes it difficult to implement relevant changes in the undergraduate CPT programme. Taken together, there is a need for a greater consensus among CPT teachers on detailed requirements for safe prescribing, to ensure that students are exposed to similar basic levels of training. This is becoming more important, given the increased cross-border mobility of medical students and junior doctors [93].

Notwithstanding the lack of a consensus on essential competencies, we identified 47 articles reporting a general lack of students' preparedness, self-confidence, (self-reported) knowledge and skills, specifically regarding general prescribing, antimicrobial prescribing and pharmacovigilance. These findings are in line with previous literature reviews reporting that medical graduates feel particularly unprepared for prescribing relative to their preparedness for other clinical competencies (e.g. history taking and physical examination) [94, 95]. This lack of competence could at least partly explain the relatively high number of prescribing errors made by junior doctors, and is probably due to inadequate CPT education during the undergraduate medical curriculum. Indeed, recent studies have reported that CPT education is still based mainly on traditional learning methods (e.g. lectures and oral exams) [11], and is often not taught and assessed separately because the subject is integrated into broader course designs [62].

What can be done? To improve CPT education in undergraduate European medical curricula, we recently formulated a list of recommendations that could also be useful elsewhere (e.g. the USA) [11]. More emphasis should be given to training medical students in clinical practice, preferably as early as possible during medical training, with students being responsible for patient care under the supervision of a senior clinician [96]. Moreover, prudent antibiotic prescribing and pharmacovigilance should be given more attention as many studies reported that students felt that there was a lack of training in these two subjects. However, as prescribing errors are caused by multiple factors, changing undergraduate CPT education is only part of the solution, and multifaceted interventions in clinical practice are needed that address the different aspects of the prescribing process [97].

Although our findings are worrying, the results should be interpreted with caution, given the heterogeneity and methodological weaknesses of the included studies.

Studies were generally of a single-institution design and of low-to-moderate quality (mean MERSQI score 10.5), and different evaluation methods were used without their validity and reliability being reported. Moreover, as the vast majority of studies (96%) measured 'soft endpoints' (Kirkpatrick levels 1 and 2) in a controlled setting, it can be questioned whether the same results would be found in clinical practice. It is unlikely that competence in this context would be better, given the high workload, stress and distractions on hospital wards. Taken together, we conclude that there is considerable evidence that final-year medical students lack the prescribing competencies required for safe prescribing.

Our review had a number of limitations. First, articles may have been missed, although we attempted to minimize the likelihood of this by searching three databases and using a snowball strategy. Second, one recent important study was not included because the search was terminated before its publication. The latter study describes the delivery of a national prescribing assessment to 7343 UK final-year medical students in 2016 [98]. Although there was significant variation in performance between final-year medical students studying in different UK medical schools, their overall performance was good (95% passed the test). The study shows that the introduction of a valid and reliable national prescribing assessment is a powerful tool to emphasize CPT in the medical curriculum, and to evaluate and improve the essential prescribing competencies of future doctors. More countries should consider implementing a similar national prescribing assessment. Third, the cross-sectional studies were small and had low response rates. Fourth, a number of potentially relevant studies were excluded because they did not mention students' year of training. Fifth, the prescribing competencies of students might have been underestimated as a result of publication bias that favoured negative outcomes.

Conclusion

Taking these limitations into consideration, there is considerable evidence that final-year medical students have insufficient prescribing competencies, which suggests that changes in undergraduate CPT education are required urgently. Moreover, there is a need for a greater consensus among CPT teachers on the competencies that are essential to ensure that medical students prescribe safely and effectively. Steps are being taken to build a European consensus among CPT experts. The Education Working Group of the European Association of Clinical Pharmacology and Therapeutics is conducting a new Delphi study to achieve a consensus on learning outcomes that should be common to all European undergraduate CPT curricula. Future studies should investigate valid and reliable methods for assessing students' prescribing competencies in clinical practice, especially as current studies lack quality and mainly evaluate competencies in a controlled environment. To develop evidence-based CPT education, further studies of educational interventions with Kirkpatrick's highest level of outcome are needed, preferably with a multicentre design, a large number of participants and a long follow-up. Student-run clinics may be useful for this purpose as they offer students early

prescribing experience, with real responsibility for patient care under the supervision of a senior clinician [99].

Competing Interests

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Supporting Information

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Appendix S1 Search strategy performed in PubMed, Excerpta Medica Database (EMBASE) and Education Resources Information Center (ERIC) databases on 10 January 2017

Appendix S2 Best Evidence Medical Education (BEME) Collaboration coding sheet

Appendix S3 General prescribing competencies mentioned by more than one study