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Effectiveness of teaching evidence-based medicine to undergraduate medical students: A BEME systematic review

SEYED-FOAD AHMADI[1,2], HAMID R BARADARAN[1] & EMAD AHMADI[3,4]

[1]Iran University of Medical Sciences, Iran, [2]University of California Irvine, USA, [3]Tehran University of Medical Sciences, Iran, [4]Harvard Medical School, USA

Abstract

Background: Despite the widespread teaching of evidence-based medicine (EBM) to medical students, the relevant literature has not been synthesized appropriately as to its value and effectiveness.

Aim: To systematically review the literature regarding the impact of teaching EBM to medical students on their EBM knowledge, attitudes, skills and behaviors.

Methods: MEDLINE, SCOPUS, Web of science, ERIC, CINAHL and Current Controlled Trials up to May 2011 were searched; backward and forward reference checking of included and relevant studies was also carried out. Two investigators independently extracted data and assessed the quality of the studies.

Results: 10,111 potential studies were initially found, of which 27 were included in the review. Six studies examined the effect of clinically integrated methods, of which five had a low quality and the other one used no validated assessment tool. Twelve studies evaluated the effects of seminars, workshops and short courses, of which 11 had a low quality and the other one lacked a validated assessment tool. Six studies examined e-learning, of which five having a high or acceptable quality reported e-learning to be as effective as traditional teaching in improving knowledge, attitudes and skills. One robust study found problem-based learning less effective compared to usual teaching. Two studies with high or moderate quality linked multicomponent interventions to improved knowledge and attitudes. No included study assessed the long-term effects of the teaching of EBM.

Conclusions: Our findings indicated that some EBM teaching strategies have the potential to improve knowledge, attitudes and skills in undergraduate medical students, but the evidenced base does not demonstrate superiority of one method. There is no evidence demonstrating transfer to clinical practice.

Practice points

- Although several systematic reviews have explored various aspects of evidence-based medicine (EBM), no prior study has attempted to systematically review the effectiveness of teaching EBM to undergraduate medical students.
- We systematically reviewed the studies of clinically integrated methods of teaching EBM, short courses and instructions, e-learning, problem-based learning and other multicomponent interventions. However, we drew no net conclusion since the included studies were either weak, few or inconsistent.
- In general, teaching EBM has the potential to improve knowledge, attitudes and skills in undergraduate medical students. However, evidence supporting the effect of EBM teaching on students' behaviors is currently insufficient.
- We suggest future studies to focus on assessing long-term higher-order mastery of EBM and use robust methods and high-quality assessment tools.

Introduction

Evidence-based medicine (EBM) is "the conscientious, explicit and judicious use of current best evidence in making decisions about the care of individual patients" (Sackett et al. 1996). The practice of EBM usually requires the following five steps: (1) Translating the uncertainties into answerable questions (asking); (2) searching for and retrieving evidence to answer the questions (acquiring); (3) critically appraising the evidence for validity and clinical importance (appraising); (4) applying the appraised evidence to inform the clinical decisions (applying); and (5) evaluating the performance in the previous four steps (assessing) (Dawes et al. 2005).

The teaching of EBM has become increasingly popular in both undergraduate and postgraduate medical education programs worldwide (Crilly et al. 2009). EBM is now a component of the foundation years training program in the UK (Colleges 2007), the focus of graduate assessment in the United States (Stewart 2001) and a requirement of practicing physicians in Canada (Frank et al. 2005). However, there is

Correspondence: Hamid R Baradaran, Associate Professor of Clinical Epidemiology/Deputy of Research, Center for Educational Research in Medical Sciences, Iran University of Medical Sciences, Zip Code: 14496-14535, Tehran, Iran. Tel: +98-21-86702216; Fax: +98-21-86702237; E-mail: baradaran.hr@iums.ac.ir

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limited robust-evidenced research that has examined the teaching methods of EBM (Hatala & Guyatt 2002).

EBM experts have systematically reviewed the literature regarding teaching EBM to postgraduates (Coomarasamy & Khan 2004; Flores-Mateo & Argimon 2007) and allied health professionals (Dizon et al. 2012), teaching critical appraisal (Norman & Shannon 1998; Taylor et al. 2000; Parkes et al. 2001), assessing the effectiveness of journal clubs (Ebbert et al. 2001; Harris et al. 2011), evaluation methods of EBM education (Shaneyfelt et al. 2006; Walczak et al. 2010) and barriers to EBM application by residents (van Dijk et al. 2010). However, the most effective methods for teaching EBM to undergraduate medical students have remained unclear.

Hence, the aim of this systematic review was to evaluate the effect of various EBM teaching strategies on medical students' knowledge, attitudes, skills and behaviors. In addition, the teaching of EBM is reported to be improved by breaking it into the steps of asking, acquiring (or accessing), appraising, applying, plus an evaluating (or assessing) step (Del Mar et al. 2004). Therefore, we also examined whether the educational interventions could improve the above EBM steps.

Methods

Criteria for inclusion of studies

We included the comparative studies, i.e. randomized controlled trials (RCTs), non-RCTs and self-controlled trials that: (A) had recruited undergraduate medical students (defined as medical school students who have not yet enrolled in the residency programs), (B) had carried out at least one educational intervention (defined as coordinated educational activity, of any medium, duration or format) to teach EBM and (C) had objectively assessed the impact of the intervention(s) on students' knowledge, attitudes, skills or behaviors using tests, questionnaires, clinical performance, etc. Self-reported perceived knowledge, skills or behaviors were not eligible since they are loosely connected to their objective measurements (Khan et al. 2001; Caspi et al. 2006).

Identification and selection of studies

We searched the following databases up to May 2011: MEDLINE, SCOPUS, ISI Web of Science, Educational Resource Information Center (ERIC) and Cumulative Index to Nursing and Allied Health Literature (CINAHL) using the following search strategy:

> ((evidence-based medic*) OR (evidence based medic*) OR (evidence-based practic*) OR (evidence based practic*) OR (critic* AND apprais*) OR (pre-filter*) OR (prefilter*) OR (pre-digest*) OR (predigest*)) **AND** (educat* OR teach* OR cours* OR workshop* OR learn* OR instruct* OR curriculum* OR (journal* AND club*) OR (case discuss*)) **AND** (student* OR intern OR interns OR internship* OR (clinical clerk*) OR undergraduat*).

We also searched the Current Controlled Trials for relevant unpublished studies. For this purpose, we tailored the above search strategy accordingly. Furthermore, we performed a backward and forward reference checking by (A) screening the references of our included studies and relevant systematic reviews and (B) screening the studies that have cited any of our included studies as their references (citation checking). We performed the latter using Science Citation Index and SCOPUS.

The retrieved studies were imported into EndNote X3 software (Thomson Reuters, Philadelphia, PA), and the duplicated studies were removed. The remaining studies were subsequently screened for inclusion based upon their titles and abstracts initially and their full-text finally. One of the two investigators (S. F. A. and E. A.) decided upon including each study (this step was not performed in duplicate).

Data abstraction and risk of bias assessment

Two investigators (S. F. A. and E. A.) independently summarized the study characteristics, key results and quality indicators using an electronic data abstraction form in Microsoft Excel Software. Disagreements between the two investigators were resolved by third reviewer negotiation. For studies with unclear or inadequate results, we sent an electronic data abstraction form to the corresponding author and requested further details.

For quality assessment, two sets of criteria were used: (A) a set of criteria developed by the Cochrane Effective Practice and Organization of Care group (Parkes et al. 2001) and "using validated assessment tools" criterion (the investigators used this set to code the overall risk of bias as high, moderate or low) and (B) a modified version of another criteria developed by Reed et al. to appraise the reports of medical education interventions (Reed et al. 2005). These criteria are available in Supplementary Table 2.

Synthesis of results

We synthesized the results qualitatively by tabulating the characteristics of the included studies (Table 1) and whether they fulfill the quality criteria (Supplementary Table 2). Tables 1 and 2 are available as Supplementary Material at www.informahealthcare.com. We also classified the studies based on their interventions and discussed the effects of the interventions on the knowledge, attitudes, skills and behaviors of asking, acquiring, appraising and applying.

Inter-rater agreement was quantified using Kappa scores. To calculate the Kappa scores for our data abstraction, we compared the codes that the two investigators assigned to the study designs, intervention categories and assessment types of the included studies (Table 1). To calculate the Kappa scores for our quality assessments, we compared the assigned codes to the quality criteria (Supplementary Table 2).

We attempted to meta-analyze the results of the studies with similar outcome assessments and with minimal diversity in their study designs, participants and interventions. However, we found few studies with the above characteristics and therefore felt meta-analysis to be an inappropriate statistical endeavor in this context.

Table 1. Characteristics of included studies.

Study ID	Design, setting and participants	Interventions (teaching methods)	Outcomes (assessment)	Key results
(West et al. 2011)	SCT in Mayo Medical School, USA (2006–2008) on 99 second-year medical students	Integrated method: I. 20–22 h lectures plus small-group discussions in EBM principles and appraisal of various study types in second year, II. Electronic feedback on developing CATs from real patients in 6–7 rotations of third year.	Validated: Survey with Berlin Questionnaire and/or Fresno Test prior to and after short course, and upon completion of third year.	Knowledge and skills of EBM: improved
(Sastre et al. 2011)	SCT in Vanderbilt Medical School, USA (2007–2008) on 100 third-year medical students	Short instruction: Three-hour workshop in asking, acquiring and pros and cons of pre-appraised sources.	Partly validated[a]: Pre- and post-workshop analysis of computer log data of searches, expert scoring of EBM content in clerkship notes, and survey to assess attitudes toward EBM and acquiring.	Behaviors of acquiring and applying and Attitudes toward EBM and acquiring: improved
(Lai & Nalliah 2010)	SCT in International Medical University of Malaysia (2005–2006) on 65 final-year medical students	Integrated method: I. Two sessions in EBM principles, acquiring and appraising, II. Electronic exploratory notes, III. 6 × 2-h small-group bedside sessions to exercise asking, IV. Self-searching, V. Presenting CATs in journal clubs, VI. EBM reports in portfolios.	Validated: Pre- and post-course questionnaire to assess preferred information sources.	Attitudes toward acquiring: unchanged
(Hadley et al. 2010)	Cluster RCT in seven teaching hospitals in UK West Midlands (2007) on 237 Interns (Foundation year 2 doctors)	e-learning: Intervention A: Three-hour session with modules in asking, acquiring, and appraising; Intervention B: Six-week web access to e-learning modules in the same topics.	Validated: Module-specific multiple-choice questions to assess knowledge before and after each module.	Knowledge of asking, acquiring and appraising: comparable
(Aronoff et al. 2010)	SCT in Temple University, USA (2005) on 153 third-year medical students	Integrated method: I. 18-week access to 6 online modules, plus supervised assignments in asking, acquiring, appraising various study types and applying, II. Completion of four CATs from real patients.	Validated: Pre- and post-course Fresno Test.	Skills of EBM: improved
(Lai & Teng 2009)	SCT in International Medical University of Malaysia (2006) on 72 Final-year medical students	Integrated method: I. Two sessions in EBM resources and appraising plus electronic exploratory notes, II. 6 × 2-h small-group bedside sessions to exercise asking, III. Self-searching, IV. Presenting CATs in journal clubs, V. Developing EBM reports in portfolios.	Validated: Pre- and post-course Modified Fresno Test.	Skills of EBM: improved
(Johnston et al. 2009)	Cross-over RCT in University of Hong Kong (2007) on 129 second-year medical students	Problem-based learning: Intervention A: 4 × 4-h usual teaching sessions to practice asking, acquiring, appraising, and applying; Intervention B: 4 × 4-h problem-based learning sessions to practice the same steps.	Validated: Before, post-phase 1, and post-phase 2 KAB Questionnaire to assess EBM knowledge, personal application and current and future use of EBM, and attitudes toward EBM.	Knowledge of and attitudes toward EBM: favor usual teaching.
(Taheri et al. 2008)	SCT in Isfahan University of Medical Sciences, Iran (2005) on 24 fifth- and sixth-year medical students	Short instruction: Four-day workshop (each day: two-hour lecture + 1-h small-group session) in asking, acquiring, appraising and applying.	Validated: Pre- and post-workshop questionnaire to assess knowledge of asking, plus expert evaluation of acquiring.	Knowledge of asking and skills of acquiring: improved
(Davis et al. 2008)	RCT in University of Birmingham, UK (2006) on 229 first-year medical students	e-learning: Intervention A: 40-min computer based session to teach asking, acquiring, appraising, and applying; Intervention B: 40-min lecture based session to teach the same topics.	Validated: Pre- and post-session questionnaire to measure EBM knowledge and attitudes.	Knowledge of EBM: comparable; attitudes toward EBM: *mostly* comparable

(continued)

Table 1. Continued

Study ID	Design, setting and participants	Interventions (teaching methods)	Outcomes (assessment)	Key results
(Lee et al. 2007)	RCT in Chinese University of Hong Kong (2005) on 155 fifth-year medical students	Multicomponent: Intervention: teaching about performing and appraising decision, sensitivity, and cost-effectiveness analyses through: I. reading a handbook, II. 3 × 40-min lectures, III. One-hour small-group session, IV. home-appraising, V. 1-hour workshop on using software. Control: none.	Non-validated: Pre- and post-course questionnaire to assess knowledge of decision analysis, sensitivity analysis graphs and cost-effectiveness ratios.	Knowledge of apply subsets: *partly* improved
(Davis et al. 2007)	RCT in five teaching hospitals in UK West Midlands (2005) on 55 Interns (foundation year 1 doctors)	e-learning: Intervention: 40-min computer based session in asking, acquiring, appraising and applying; Control: 40-min lecture based session in the same topics.	Validated: Pre- and post-session questionnaire to measure EBM knowledge and attitudes.	Knowledge of and attitudes toward EBM: comparable
(Schilling et al. 2006)	RCT in Boston University, USA, on 238 third-year medical students	e-learning: Intervention: Four-week web access to four online modules in MEDLINE, pre-appraised sources, Study designs and NNT calculation; Control: none.	Partly validated: Post-course expert evaluation of captured OVID MEDLINE searches, retrieval of high-quality evidence, correct calculation of NNT and number of MEDLINE searches.	Skills of acquiring and a minor skill of applying: improved
(Krueger 2006)	RCT in University of Medicine and Dentistry of New Jersey, USA (1998–1999) on 77 third-year students of osteopathic medicine	Integrated method: Intervention: I. Lecture in EBM, II. 2 small-group discussions in appraising, III. Reading materials in applying, IV. Journal club, V. Instruction in Cochrane Library, IV. EBM assignment; Control: Lectures in other topics.	Non-validated: Post-course multiple-choice question Critical Appraisal Examination to assess appraising knowledge/skills.	Knowledge/skills of appraising: improved
(Bolboaca & Jantschi 2006)	SCT in Iuliu Hatieganu University of Medicine and Pharmacy, Romania (2005) on 40 fourth- to sixth-year medical students	e-learning: Three-month access to a CD-ROM e-course consisting of: I. 14 tutorials in EBM steps and appraising various study types plus self-evaluation tests, II. Supplementary material including glossary, Romanian guidelines, and relevant papers and software.	Non-validated: Pre- and post-e-course test of EBM knowledge.	Knowledge of EBM: improved
(Weberschock et al. 2005)	SCT in Johann Wolfgang Goethe University, Germany (2003–2004) on 132 third-year medical students	Short instruction: 4 × 3-h EBM lectures and small-group discussions in EBM principles and asking, acquiring through MEDLINE and applying therapy and diagnosis studies.	Validated: Pre- and post-course Question papers (two sets) to assess application of principles, and Berlin questionnaire.	Knowledge and skills of EBM: improved
(Gruppen et al. 2005)	NCT in University of Michigan, USA (2001–2003) on 92 fourth-year medical students	Short instruction: Intervention: Two-hour additional session in using Ovid MEDLINE, consisting of a brief lecture and guided hand-on practice during an EBM course; Control: EBM course alone.	Non-validated: Pre-session and one-month post-session expert scoring of the quality of a particular search using a pre-developed scoring sheet.	Skills of acquiring: improved
(Bradley et al. 2005)	RCT in University of Oslo, Norway (2002–2003) on 175 10th-semester medical students	e-learning: Intervention A: Workshop (directed learning) of 5 × 3-h sessions in asking, acquiring, appraising and applying; Intervention B: Computer-assisted modules (self-directed learning) in the same topics.	Validated: 18 weeks post intervention questionnaire to assess acquiring and appraising knowledge, expert scoring of participant-developed CATs to assess appraising skills and 1–17 weeks post intervention questionnaire to assess attitudes toward EBM.	Knowledge of acquiring, knowledge and skills of appraising and attitudes toward EBM: comparable
(Alper & Vinson 2005)	SCT in University of Missouri-Columbia, USA, on 90 third-year medical students	Integrated method: I. 90-min computer lab session in acquiring, II. Access to free internet portal, III. Handout of practical points for acquiring and applying, IV. Two acquiring assignments from real patients, V. Follow-up 90-min computer laboratory session.	Non-validated: Pre- and post-intervention student recorded time-to-answer and number of searched sites to answer three clinical questions, and expert evaluation of the quality of answers.	Skills of acquiring: improved

(Sanchez-Mendiola 2004)	NCT in Mexican Army Medical School (2001–2002) on 131 fifth- and sixth-year medical students	Short instruction: Intervention: 14 × 2-h sessions in EBM; Control: none.	Validated: Post-course questionnaire to assess attitudes towards acquiring and self-reported preferred information sources, plus knowledge of EBM.	Attitudes toward acquiring: improved; knowledge of EBM: unchanged
(Dorsch et al. 2004)	SCT in University of Illinois, USA (2000–2001) on 36 third-year medical students	Integrated method: I. 8 × 1-h weekly seminars plus pre-session reading materials in EBM principles and asking, acquiring, and appraising diagnosis, therapy and meta-analysis studies; II. Developing and presenting CATs from real patients in three sessions.	Non-validated: Pre- and post-seminar self-reported frequently used information sources, and expert scoring of written test of EBM steps.	Attitudes toward acquiring and skills of asking and acquiring: *minimally* changed; skills of appraising: *partly* changed
(Leung et al. 2003)	Cross-over RCT in University of Hong Kong (2001) on 169 fourth-year medical students	Multicomponent: Intervention ‘‘P’’ (Pocket Card): 2 × 2-h sessions in EBM principles, asking, acquiring, and applying; using pocket card of EBM guides; and supervised practicing of EBM steps; Intervention ‘‘I’’ (InfoRetriever): similar to ‘‘P", but PDA with InfoRetriever and digital pocket card was also provided; Control (C): none.	Validated: Baseline and post-phase 1–3 questionnaires to assess personal applications well as current and future use of EBM.	Attitudes toward EBM: improved by Pocket Card, *further* improved by InfoRetriever.
(Fritsche et al. 2002)	SCT in various short EBM courses in Germany (1999–2001) on 203 third-year medical students	Short instruction: Three-day course in EBM principles and in asking, appraising, and applying plus using pre-appraised evidence and estimating risk, benefit and harm.	Validated: 0–4 weeks pre- and post-workshop Berlin Questionnaire.	Knowledge and skills of EBM: improved
(Rosenberg et al. 1998)	RCT in Oxford University, UK, on 108 first-year clinical students	Short instruction: Intervention: Three-hour small-group session in asking and acquiring through WinSpirs MEDLINE; Control: none.	Non-validated: Pre- (in intervention group) and post-session expert scoring of search strategies and number and quality of retrieved citations.	Skills of acquiring: improved
(Landry et al. 1994)	NCT in four army universities in DC (Intervention), and Maryland, OH and Texas (Control), on 146 third-year clinical clerks	Short instruction: Intervention: 2 × 90-min seminars in types of medical literature and study design, and in appraising diagnostic test and therapy articles; Control: none.	Non-validated: One-week pre-seminars and five-weeks post-seminars expert scoring of literature use in patient write-ups.	Behavior of acquiring: unchanged
(Frasca et al. 1992)	NCT in two campuses of University of Illinois, USA, on 92 third-year clinical clerks	Short instruction: Intervention: I. 10 × 1.5-h sessions in acquiring and appraising diagnostic test, prognosis, etiology or causation and therapy effectiveness studies, II. Supervised development of a CAT; Control: none.	Non-validated: Post-course questionnaire to assess acquiring skills and appraising knowledge.	Skills of acquiring and knowledge of appraising: improved
(Bennett et al. 1987)	NCT in McMaster University, Canada, on 92 Final-year clinical clerks	Short instruction: Intervention: 8 × 2-h small-group sessions to teach appraising diagnostic test and therapy effectiveness studies; Control: none.	Non-validated: Pre- and post-sessions expert scoring of appraising a diagnostic test and two therapy effectiveness studies.	Skills of appraising: improved
(Radack & Valanis 1986)	NCT in University of Cincinnati, USA (1984–1985) on 34 fourth-year clinical clerks	Short instruction: Intervention: 5 × 50-min small-group sessions in appraising clinical measurement, diagnostic testing, and therapeutic efficacy; Control: none.	Non-validated: Pre- and post-sessions unidentified test of appraising diagnosis and therapy.	Skills of appraising: unchanged

SCT, self-controlled trial; CAT, critically appraised topic; RCT, randomized controlled trial; NCT, non-randomized controlled trial.
[a]Partly validated: Asubset (and not all) of outcomes were assessed using validated assessment tools.

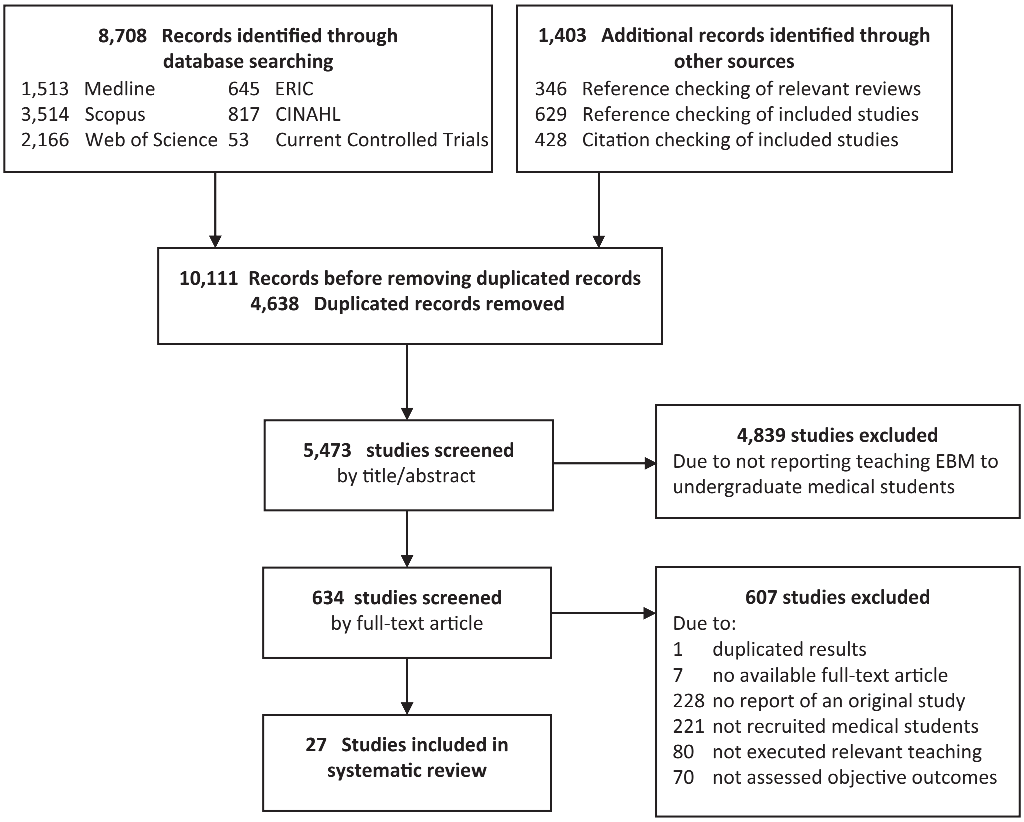

Figure 1. Flow diagram of study selection.

Results

Description of included studies

We retrieved 10,111 records in total, of which 27 were included in this study (Figure 1). Included studies with non-randomized designs and high risks of bias were predominant: The number of self-controlled trials, parallel non-RCTs and RCTs was 11, 6 and 10, respectively (Table 1). In addition, the number of studies with a high, moderate and low risk of bias was 17, 5 and 5, respectively (Supplementary Table 2). No included study evaluated the long-term effects of the intervention(s), and only 16 studies reported their results in adequate detail (Supplementary Table 2). Kappa values were 0.87, 0.69 and 0.72 for the inter-rater agreement in data abstraction and in the two parts of the quality assessment, respectively.

Effects of clinically integrated methods

The teaching of EBM is believed to be more effective if it is integrated into clinical practice (Coomarasamy & Khan 2004). We identified seven studies evaluating such clinically integrated methods (Dorsch et al. 2004; Alper & Vinson 2005; Krueger 2006; Lai & Teng 2009; Aronoff et al. 2010; Lai & Nalliah 2010; West et al. 2011), while the remaining 20 studies evaluated standalone methods in no clinical practice context. Dorsch et al. reported the earliest clinically integrated teaching of EBM to the students, in which they observed slightly improved asking skills, acquiring attitudes and skills and appraising skills (Dorsch et al. 2004). Another study also observed no effect of a clinically integrated method on acquiring attitudes (Lai & Nalliah 2010). However, they reported no *a priori* sample size calculation; thus, they might lack sufficient power to detect a possibly existent educational effect.

The other five studies of clinically integrated methods reported improved acquiring skills (Alper & Vinson 2005), appraising knowledge and skills (Krueger 2006) and EBM knowledge (West et al. 2011) and skills (Lai & Teng 2009; Aronoff et al. 2010; West et al. 2011). However, four of them had a high risk of bias (Supplementary Table 2), and the only exception – with a moderate risk of bias – lacked a validated assessment tool (Krueger 2006). In addition, in one of these five "positive" studies, participants who were educated earlier received lower post-test scores, which indicates that the educational effect might be short-term (Lai & Teng 2009).

Effects of short instructions

Eleven studies examined the effect of seminars, workshops and short courses (Radack & Valanis 1986; Bennett et al. 1987; Frasca et al. 1992; Landry et al. 1994; Rosenberg et al. 1998; Fritsche et al. 2002; Sanchez-Mendiola 2004; Gruppen et al. 2005; Weberschock et al. 2005; Taheri et al. 2008; Sastre et al. 2011), from which two studies reported no effect on acquiring behavior or appraising skills (Radack & Valanis 1986; Landry et al. 1994), and another study reported no effect on EBM knowledge but improved attitudes toward the use of scientific evidence (Sanchez-Mendiola 2004). The other eight studies found positive effects. However, 10 of these 11 studies had a high risk of bias, and the only exception with an acceptable quality (Rosenberg et al. 1998) lacked a validated assessment tool (Supplementary Table 2).

Notably, in the study by Weberschock et al., medical students successfully delivered the compulsory EBM course to their peers, which yielded improved knowledge and skills of EBM (Weberschock et al. 2005).

Effects of e-learning

Six studies investigated the effects of the online or computer-assisted courses and instructions (Bradley et al. 2005; Bolboaca & Jantschi 2006; Schilling et al. 2006; Davis et al. 2007, 2008; Hadley et al. 2010), from which three studies with a low risk of bias reported computer-assisted sessions to be as effective as usual teaching sessions in teaching acquiring knowledge, appraising knowledge and skills and EBM knowledge and attitudes, generally (Bradley et al. 2005; Davis et al. 2007, 2008). Similarly, another study with a moderate risk of bias found online modules similarly effective as usual teaching in training asking, acquiring and appraising knowledge (Hadley et al. 2010).

The other two studies compared e-learning with no intervention: one study linked an online module to improved skills of acquiring and calculation of number needed to treat (Schilling et al. 2006), while the other study correlated a CD-ROM e-course to improved EBM knowledge (Bolboaca & Jantschi 2006). However, the former used no validated assessment tool – despite its acceptable quality – and the latter had a high risk of bias (Supplementary Table 2).

Effects of problem-based learning

Johnston et al. compared a stand-alone problem-based learning intervention with usual teaching in a high-quality study (Supplementary Table 2) and found "usual" teaching more favorable in improving EBM knowledge and attitudes (Johnston et al. 2009).

In another study from McMaster University (the pioneer of problem-based learning), educators used problem-based material, but no real problem-based learning strategy to teach EBM (Bennett et al. 1987); therefore, their results were not elaborated in this study.

Effects of other multi-component interventions

Lee et al. compared a multi-component intervention – consisting of short courses plus self-reading and practice – with no intervention in a RCT and observed an improved knowledge of decision analysis, but no improved knowledge of cost-effectiveness or sensitivity analyses (Lee et al. 2007). The authors presented their intervention as a clinically integrated teaching method; however, we categorized their teaching as stand-alone since their teaching was not carried out in a clinical context. This study also used no validated assessment tool (Supplementary Table 2). Furthermore, their intention-to-treat analysis is questionable since participants consented to enter the study after being randomly allocated, and those who did not consent were not included in analyses.

In a cross-over RCT, Leung et al. compared the effects of adding the following interventions to a workshop: (A) Providing guides and "InfoRetriever" on personal digital assistants (PDAs); (B) providing educational pocket cards of the same guides; and (C) no intervention (Leung et al. 2003). They observed improved perceptions regarding the use of EBM and the integration of EBM in clinical teaching in both active arms although the PDA arm yielded a larger effect. Notably, despite the researchers' potential control over participants' assignment and study design, the participants were rotated through the three study arms in a disorganized manner, and neither the total number of experiments per arm nor the crossing-over order was balanced. However, the study had a low risk of bias (Supplementary Table 2).

Discussion

The findings of this systematic review showed that teaching EBM has the potential to improve knowledge, attitudes and skills in undergraduate medical students. However, there is still insufficient evidence to support the statement that EBM teaching either improves students' behaviors or yields a long-term mastery of EBM. In addition, we found no study assessing patient outcomes or health delivery processes, possibly because undergraduate students would be rarely the final decision makers regarding patient management. Studies of the clinically integrated methods and short instructions were weak and inconsistent. In contrast, a number of robust studies supported the use of e-learning strategies. A single strong study found problem-based learning less effective than usual teaching. Finally, few studies linked other multicomponent interventions to improved knowledge and attitudes.

Our study as well as other systematic reviews has found the studies of EBM teaching generally weak (Taylor et al. 2000; Ebbert et al. 2001; Parkes et al. 2001; Flores-Mateo & Argimon 2007; Harris et al. 2011). However, the lack of high-quality evidence is not merely confined to the teaching of EBM, but it is an universal dilemma for the teaching of various sciences (Hatala & Guyatt 2002). Therefore, we should not under-value the teaching of EBM to undergraduate medical students due to the lack of insufficient robust evidence. Instead, we should focus on providing robust evidence by the conduct of the future studies in higher qualities with a focus on the skills and behaviors as well as the long-term educational effects. Only two of our included studies measured behaviors following the educational interventions (Landry et al. 1994; Sastre et al. 2011).

Although we did not aim to appraise the validity of the assessment tools of our included studies, another review (Shaneyfelt et al. 2006) found that only seven of our included studies have high-quality assessment tools (Bennett et al. 1987; Bradley et al. 2005; Fritsche et al. 2002; Weberschock et al. 2005; Lai & Teng 2009; Aronoff et al. 2010; West et al. 2011). When we attempted to pool the results of the included studies, we ended up with no more than five studies (Fritsche et al. 2002; Lai & Teng 2009; Weberschock et al. 2005; Aronoff et al. 2010; West et al. 2011) since the other included studies had used miscellaneous tools rather than established validated tools such as Fresno Test or Berlin Questionnaire. Using similar assessment tools would enable the researchers to quantitatively pool the results together in meta-analyses, which yields larger statistical powers and improved generalizability. Selection of the assessment tools should be based on not only their quality, but also their purpose. As an example, although the Berlin Questionnaire and the Fresno Test are both established assessment tools, the former is designed to test applied knowledge through its multiple-choice format, thus it should be avoided in evaluating the skills of asking or acquiring. On the other hand, the latter is suitable to test the knowledge and skills across the four steps of EBM (West et al. 2011).

Our systematic review also calls for more robust studies of the clinically integrated methods. Notably, our included studies examined no ideal "on foot" EBM teaching as described elsewhere (Richardson 2005). In addition, our included studies of the clinically integrated methods were inconsistent and of low quality.

A systematic review (Coomarasamy & Khan 2004) has found that in postgraduate medical professionals, clinically integrated methods would improve their EBM knowledge, attitudes, skills and behaviors, while standalone methods would improve only knowledge and possibly skills. In contrast, our results have indicated that for undergraduate students, standalone methods are able to improve not only the EBM knowledge but also the attitudes and skills. This may be because students are hypothetically driven by external factors such as the curriculum and the assessments. Such factors are possibly addressed by either stand-alone or clinically integrated methods. In contrast, postgraduates are usually driven by self-motivation and relevance to clinical practice, which are properly addressed by clinically integrated methods only (Coomarasamy & Khan 2004). This argument is supported by another systematic review in which standalone instructions in critical appraisal improved the knowledge of undergraduate students, but such instructions yielded limited knowledge gain in residents (Norman & Shannon 1998).

A robust systematic review by Hartling et al. drew no net conclusion about the effectiveness of problem-based learning for undergraduate medical education because of the inconsistencies in the included studies (Hartling et al. 2010). Another systematic review linked problem-based learning in medical school to post-graduation improvements, but mainly in social and cognitive competencies rather than in clinical knowledge and skills (Koh et al. 2008). Our single identified study of teaching EBM by problem-based learning methods found it less favorable than usual teaching (Johnston et al. 2009). However, this study was in Hong Kong where didactic teaching is culturally dominant, and the successful delivery of interactive approaches is challenging (Khan & Coomarasamy 2006). In addition, this study was brief while effective problem-based learning methods usually need substantial student–educator interactions (Koh et al. 2008). Researchers inferred that students may need to initially learn the basics and subsequently receive problem-based learning in order to successfully grasp the skills to apply their knowledge (Khan & Coomarasamy 2006). Considering the above argument, we were unable to draw net conclusions regarding the true effects of problem-based learning.

A systematic review by Cook et al. (2008) found the internet-based learning strategies as effective as traditional teaching methods. Their findings are in line with the findings of our included studies, particularly the three high-quality studies of computer assisted sessions. Since e-learning can provide a wide spectrum of teaching strategies, it may make learning more exciting, effective and likely to be retained (Greenhalgh 2001). However, our included studies of e-learning assessed no behavior, and only one study assessed skills (of acquiring and applying) (Schilling et al. 2006). This is possibly because higher order impacts (such as improved behaviors) result from interactive rather than deductive interventions (Greenhalgh 2001), while none of our included studies of e-learning adopted an ideally interactive e-learning strategy. In addition, the best EBM teaching models occur at the bedside (Richardson 2005), which e-learning cannot easily recreate it. Therefore, e-learning should be considered as a complement for – rather than a substitute of – clinically integrated bedside models to teach EBM.

Straus et al. (2010) have previously distinguished the "using mode" from the "doing mode" of practicing EBM. In the "using mode", physicians search within pre-appraised sources, thus they bypass the time-consuming appraising step. Although the previous studies of the EBM education are majorly focused on the "doing mode" and particularly "critical appraisal" (Hatala & Guyatt 2002), we found three studies emphasizing the "using mode" and the "searching within pre-appraised sources" (Fritsche et al. 2002; Schilling et al. 2006; Sastre et al. 2011). Moreover, another included study showed the positive effects of accessing "InfoRetriever" through PDAs (Leung et al. 2003). Since the use of such sources is linked to better clinical decision making (Alper et al. 2005), we would call for more robust studies of teaching the using mode and the skills to use pre-appraised sources.

One included study reported a successful EBM teaching by medical students (Weberschock et al. 2005). Trained students have also been reported to be as good as faculty educators in teaching clinical principles and skills (Haist et al. 1998; Tolsgaard et al. 2007; Graziano 2011). These observations can inspire a model for EBM education, particularly for institutions with limited faculty educators. However, the current evidence supporting such a model is still insufficient.

Our systematic review had a number of limitations: we had no access to EMBASE while conducting this review, thus we could not search it. In addition, despite using comprehensive search strategies, we used no abbreviated term such as EBM or EBP in our search queries. Moreover, to identify the unpublished studies, we only searched the Current Controlled Trials that includes few educational studies. Furthermore, only one investigator decided upon including each study due to the limited time and resources of the team. Thus, we cannot exclude potential biases in the identification of the including studies. Finally, we were rather strict in including only comparative studies and in appraising our included studies based on meticulous quality criteria.

Conclusions

Implications for practice

Teaching EBM has the potential to improve knowledge, attitudes and skills in undergraduate medical students. However, there is still insufficient evidence to support the statement that EBM teaching either improves students' behaviors or yields a long-term mastery of EBM. Evidence supporting the use of clinically integrated methods (i.e. educational activities integrated into clinical practice) and stand-alone short instructions (i.e. brief educational activities conducted in no real clinical practice context) are currently insufficient. However, high-quality evidence has supported that computer-assisted instructions are as effective as traditional educational strategies in improving EBM knowledge and attitudes. Nevertheless, their effects on the students' skills and behaviors are unclear. We have also drawn no net conclusion about the effectiveness of problem-based learning of EBM since only one high-quality study examined it. Finally, the effects of other multicomponent interventions were heterogeneous and inconclusive.

Implications for research

We suggest future studies of teaching EBM to medical students to focus on: (A) reporting the participants, interventions, outcomes and results in sufficient details in order to allow replication; (B) examining the effects of EBM teaching on long-term skills and behaviors using robust assessment tools; (C) evaluating appropriate "on foot", real world clinically integrated methods, problem-based learning, interactive e-learning strategies and short courses and instructions; (D) comparing the teaching of the using and the doing modes of practicing EBM; and (E) studying the student educator model to test whether trained students are able to teach EBM effectively.

Notes on contributors

SEYED-FOAD AHMADI, MD, MPH, was a Postdoctoral Fellow at Center for Educational Research in Medical Sciences, Iran University of Medical Sciences, at the time of this study; he is currently a postdoctoral fellow at Department of Medicine, University of California Irvine.

HAMID R BARADARAN, MD, PhD, is an Associate Professor of Clinical Epidemiology and the Deputy of Research at Center for Educational Research in Medical Sciences, Iran University of Medical Sciences.

EMAD AHMADI, MD, was a Postdoctoral Fellow at Digestive Diseases Research Institute, Tehran University of Medical Sciences, at the time of this study; he is currently a Postdoctoral Fellow at Department of Radiology, Massachusetts General Hospital, Harvard Medical School.

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Supplementary material available online

Supplementary Table 2.