Cognitive interventions to reduce diagnostic error: a narrative review

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ABSTRACT

Background: Errors in clinical reasoning occur in most cases in which the diagnosis is missed, delayed or wrong. The goal of this review was to identify interventions that might reduce the likelihood of these cognitive errors.

Design: We searched PubMed and other medical and non-medical databases and identified additional literature through references from the initial data set and suggestions from subject matter experts. Articles were included if they either suggested a possible intervention or formally evaluated an intervention and excluded if they focused solely on improving diagnostic tests or provider satisfaction.

Results: We identified 141 articles for full review, 42 reporting tested interventions to reduce the likelihood of cognitive errors, 100 containing suggestions, and one article with both suggested and tested interventions. Articles were classified into three categories: (1) Interventions to improve knowledge and experience, such as simulation-based training, improved feedback and education focused on a single disease; (2) Interventions to improve clinical reasoning and decision-making skills, such as reflective practice and active metacognitive review; and (3) Interventions that provide cognitive 'help' that included use of electronic records and integrated decision support, informaticians and facilitating access to information, second opinions and specialists.

Conclusions: We identified a wide range of possible approaches to reduce cognitive errors in diagnosis. Not all the suggestions have been tested, and of those that have, the evaluations typically involved trainees in artificial settings, making it difficult to extrapolate the results to actual practice. Future progress in this area will require methodological refinements in outcome evaluation and rigorously evaluating interventions already suggested, many of which are well conceptualised and widely endorsed.

INTRODUCTION

Although the rate of diagnostic error in practice is unknown, experts estimate it to be in the range of 10%–15%.[1] Diagnostic errors are of great concern in all specialties and those characterised by high levels of stress, workload and distractions are particularly vulnerable. Errors are more likely when the level of uncertainty is high, if clinicians are unfamiliar with the patient, and when there are atypical or non-specific presentations of a common disease or 'distracting' comorbid conditions.[2]

Diagnostic errors reflect the complex interplay of system-related and cognitive factors, typically with multiple root causes identifiable in a single case.[3–6] Cognitive errors can be found in the majority of cases.[4 7] Given the dominant role that cognitive shortcomings play in contributing to diagnostic error, it is appropriate to begin considering what could be done to help minimise the likelihood of these errors. We therefore conducted an analytic review of the literature to identify interventions to reduce the likelihood of cognitive errors or error-related harm in healthcare. Interventions relating to system-related factors were discussed in a companion publication.[8]

METHODS

Our search strategy has been previously described.[8] Briefly, we sought articles, books and conference presentations relating to the prevention, reduction or mitigation of diagnostic errors in PubMed and several other medical and non-medical databases. We pursued references from these sources and asked authorities in the field of applied cognition and decision-making to recommend additional readings. Articles and books were included in this analysis if they contained results from an intervention trial or suggested an intervention to reduce cognitive-related diagnostic error. Publications that focused on development or

refinement of specific diagnostic tests or technologies, or solely on the aetiology or epidemiology of error, or dealt primarily with provider satisfaction or preferences were excluded.

A full-text review using an approach described by Gordon and Findley[9] was performed on the 42 empirical studies that tested an intervention. Nineteen quality-based criteria were independently extracted from each article using a data extraction form (online appendix A). Items answered with 'yes' or 'no' included literature review described, clear objectives reported, study design reported, appropriate design to address objectives, control group used, subjects randomised, blinding used, intervention clearly described, resources described, outcomes match objectives, statistical tests used, statistical tests appropriate, data collection replicable, study replication possible and limitations discussed. Additional items assessed were the study design, subject characteristics and number of subjects. Based on these items, we assigned an 'Outcomes Rating' and 'Strength of Conclusions' rating to each article (detailed instruments in online appendix B). The Outcomes Rating was based on Kirkpatrick's hierarchy[9 10] that we slightly modified for use in assessing diagnostic errors. This hierarchy demonstrates the level of impact of each intervention on diagnostic errors (eg, Level 2b refers to an intervention in which an acquisition of concepts might impact diagnostic error, whereas Level 4b refers to an intervention that directly reduces diagnostic error). The Strength of Conclusions of each study was rated on a numerical scale (1–5) in accordance with Best Evidence in Medical Education guidelines.[9 11] This rating is not an assessment of the overall methodological quality, but is a measure of how well the conclusions made are supported by the data presented.

Two reviewers with expertise in cognitive psychology (ANDM and VLP) assessed each of the intervention studies independently. We assessed agreement between the reviewers for the Outcomes Rating and the Strength of Conclusions with Cohen's κ statistic. Differences were resolved by discussion between the two reviewers and in cases of disagreement, another investigator (SK) reviewed and rated the article. In these cases, we used consensus among these three reviewers to determine the final ratings.

Based on a prior classification scheme,[1] all articles were assigned to one of three natural categories: (1) Interventions that increase medical knowledge and experience; (2) Interventions that improve clinical reasoning; and (3) Interventions that involve getting help. Articles were further subdivided into more specific types of interventions (such as 'focused training on specific content areas', 'develop simulation exercise to expose clinicians to a greater number and variety of cases presentations', etc.) to facilitate the synthesis of the findings (tables 1–4).

RESULTS

We identified 141 sources (articles, books and conference papers) for full review. Of these, 42 sources (tables 1–4) reported empirical studies of an intervention to reduce cognitive-based diagnostic error (and sometimes also additional suggestions for interventions), 100 sources contained only suggestions (table 5) and one had both. Some sources reported more than one suggestion.

During the full-text review of the empirical studies assessing cognitive interventions, agreement between reviewers on the Outcomes Rating was substantial (κ=0.70). Similar agreement was obtained for the Strength of Conclusions (κ=0.70). There were three articles with disagreements that were resolved by discussions with a third reviewer. We categorised the intervention studies into one of three mutually exclusive categories: (1) Interventions to increase clinicians' knowledge and experience, (2) Interventions to improve clinical reasoning and decision-making skills or (3) 'Get help', interventions that assist clinicians with tools or access to other clinicians or experts. For each of these sections, we use the suggested intervention and background literature to first provide context, following which we discuss the tested interventions. The Outcomes Ratings and Strength of Conclusions ratings for each intervention article are included in tables 1–4.

1) Increase knowledge and experience

Diagnostic error could potentially be reduced by increasing physician's structured knowledge and experience, the essential basis of expertise.[143] By definition, experts will tend to make the fewest errors, have the best degrees of calibration and excel in efficient diagnosis.[50 144 145] Medical educators similarly agree with the concept of increasing experience as the key to developing expertise.[143 146 147] The interventions in this domain are summarised in table 1 and are organised into the following three categories.

Training focused on specific content areas

An effect of training on diagnostic reliability is illustrated in radiology, where certain certification programmes are based on demonstrating competency. For instance, radiologists in the UK must review 5000 mammograms a year for certification, as opposed to 480 in the USA, which may in part account for the large difference in diagnostic accuracy noted between the two countries.[54] In certain programmes, radiologists also receive

Table 1 Interventions to increase medical knowledge and experience

Author (year)	Study type and participants	Intervention	Outcome measures	Results	Conclusions	Outcomes Rating	Strength of Conclusions (1–5)
Training: focused training on specific content area							
Fridriksson *et al*[12] (2001)	Group randomised with nurses and physicians	Training on identifying subarachnoid haemorrhages.	Diagnostic errors based on subarachnoid haemorrhage rupture rates in actual patients.	Decrease in diagnostic errors.	Training can have a profound impact on diagnostic error outcome at a low cost.	4b	4
Rezvyy *et al*[13] (2008)	Before/after with psychiatrists	Addition of diagnostic coding training to general psychiatric education programme required for psychiatric recertification.	Diagnostic accuracy of clinical case vignettes after training.	Diagnostic accuracy improved more than control group whose education programme focused only on general psychiatry.	Training focused on diagnostic coding can positively affect diagnostic accuracy of case vignettes. Further research needed to determine if improvement leads to changes in routine diagnostic practice.	4b	4
Gutmark *et al*[14] (2007)	Survey with physicians (all levels)	Use of teaching database of radiology cases diagnosed accurately or inaccurately.	Physician's opinion of the collection of cases available in database.	Database most used by residents and fellows for learning and reference. Attendings used it for teaching.	Teaching databases can be useful for training and reference. Research needed to determine effects of tool on diagnostic accuracy.	3	2
Simulation: develop simulation exercises to expose clinicians to a greater number and variety of case presentations							
Bond *et al*[15] (2004)	Case series with 2nd and 3rd year emergency medicine residents	Embed cognitive error traps in cases within simulation lab to introduce cognitive forcing strategies to deal with errors. Debriefing used to review errors.	Self-report of residents' perception of benefit of intervention.	Residents said simulation was beneficial (though less than direct patient care). Increased knowledge of cognitive errors and forcing strategies. Knowledge was not actually assessed.	Educating residents on cognitive errors and forcing strategies is promising, but warrants further study and quantification of the effectiveness of educational techniques.	2b	1

Continued

Table 1 Continued

Author (year)	Study type and participants	Intervention	Outcome measures	Results	Conclusions	Outcomes Rating	Strength of Conclusions (1–5)
Carlson *et al*[16] (2011)	Before/after with 4th year medical students	Use of diagnostic reminder system (ISABEL) to reduce diagnostic error while clinicians assessed live people trained as patients or a manikin in a simulation lab.	Change in diagnostic accuracy after intervention. View of diagnostic reminder system as an education tool and resource for practice.	Diagnostic accuracy improved. Tool was viewed as beneficial as a training tool and as useful in practice.	Diagnostic reminder systems can potentially reduce cognitive-based diagnostic errors. The optimal time within training to introduce the use of such tools remains unclear. It is unclear whether diagnostic accuracy is increasing simply because of additional time spent on diagnosing problem.	2b	2
Feedback and calibration: provide intensive, detailed, specific feedback							
Tudor and Finlay[17] (2001)	Before/after with expert radiologists	Review feedback regarding diagnostic errors made diagnosing radiographs.	Diagnostic accuracy rate 4–5 months after reviewing feedback.	Diagnostic error rate in same cases decreased nominally (no statistics reported).	Allowing radiologists to review their errors may decrease diagnostic error rate. More research needed to determine if effects generalise to new cases/domain.	3	2
Wood and Tracey[18] (2009)	Group randomised control trial with doctoral students	Receiving content-based or principle-based feedback to reduce diagnostic error of overshadowing.	Reduction of overshadowing across feedback conditions.	Similar decrease in overshadowing for both feedback interventions. Less reduction in control group. Generalisation effect for content-based feedback.	Giving clinicians feedback regarding specific attributes of a case or cognitive diagnostic reasoning strategies may reduce diagnostic error involving overshadowing.	4b	4

Outcomes Ratings reflect the level of impact for each intervention on reducing diagnostic errors.[9 10] Strength of Conclusions was rated on a numerical scale (1–5) in accordance with Best Evidence in Medical Education guidelines (5=strongest).[9 11]

Table 2 Interventions to improve intuitive (system 1) and deliberate (system 2) processes in decision-making

Author (Year)	Study type and participants	Intervention	Outcome measures	Results	Conclusions	Outcomes Rating	Strength of Conclusions (1–5)
Improve system 1 processing: improve training on intuitive processing and its shortcomings							
Sherbino *et al*[19] (2011)	Case series with 4th year residents	Teaching cognitive forcing strategies to introduce diagnostic error risk, identify and countermand biases.	Diagnostic accuracy in various domains after varying delays.	After training about half the subjects still committed bias. Performance suffered even further after a delay.	Teaching cognitive forcing strategies may reduce diagnostic errors in a transferable way (though it is difficult to tell without performance measures prior to training). Also, the effects were short-lived.	3	2
Eva *et al*[20] (2007)	Randomised control trial with undergraduate psychology students	Use combined approach to reasoning including pattern recognition and careful consideration of presenting features when diagnosing ECGs with biasing information.	Diagnostic accuracy of ECG readings.	Diagnostic accuracy improved for subjects using combined reasoning approach even in presence of biasing information.	Trainees can benefit from explicit guidance of a combined approach to clinical reasoning, suggesting a value to both analytic and non-analytical reasoning tendencies.	4b	4
Improve system 1 processing: improve metacognition, intuition and reflective practice							
Mamede *et al*[21] (2010)	Before/after with 1st and 2nd year residents	Incorporation of reflective reasoning to reduce diagnostic errors.	Diagnostic errors produced before and after reflective reasoning.	Significant number or diagnoses were corrected after reflective reasoning, presumably reducing bias.	Diagnostic accuracy may be improved with reflective reasoning. More research needed to disentangle reflective reasoning from additional time assessing a case to determine if reflection generalises to experts.	3	2

Continued

Table 2 Continued

Author (Year)	Study type and participants	Intervention	Outcome measures	Results	Conclusions	Outcomes Rating	Strength of Conclusions (1–5)
Coderre *et al*[22] (2010)	Before/after with 1st year medical students	Have students reflect on initial hypothesis established prior to reviewing all clinical evidence. Then present additional concordant or discordant evidence.	Diagnostic accuracy.	With discordant data, significant increase in diagnostic accuracy. No difference in accuracy with concordant data. Overall, no significant difference in diagnostic accuracy.	Providing students with additional information after an initial diagnosis affects diagnostic accuracy differently depending on the type of information received. More research needed to determine validity of the intervention.	3	1
Improve system 1 processing: consider alternatives, consider the opposite, use prospective hindsight, think like an outsider							
Wolpaw *et al*[23] (2009)	Randomised control trial with 3rd year medical students	Incorporation of SNAPPS technique during case presentation to facilitate learning.	Diagnostic reasoning measures including number of minutes to present findings, was summary concise and thorough, etc.	SNAPPS group showed more diagnostic reasoning than a feedback comparison and a control group.	Using the SNAPPS technique may result in correction of flawed reasoning, reduction of diagnostic and therapeutic errors. Study only measured amount of reasoning and not accuracy thereof, so it is unclear how this intervention would improve diagnostic accuracy.	2b	3

Outcomes Ratings reflect the level of impact for each intervention on reducing diagnostic errors.[9 10] Strength of Conclusions was rated on a numerical scale (1–5) in accordance with Best Evidence in Medical Education guidelines (5=strongest).[9 11] SNAPPS: Summarize history and findings, Narrow the differential, Analyze the differential, Probe preceptor about uncertainties, Plan management, Select case-related issues for self-study.

Table 3 Interventions: help from other people

Author (year)	Study type and participants	Intervention	Outcome measures	Results	Conclusions	Outcomes Rating	Strength of conclusions (1–5)
			Second opinions in pathology				
Raab *et al*[24] (2008)	Before/after with expert cytologists	Use of second readings pre sign-out at three instutions, comparing random reviews to organ-targeted reviews.	Proportion of diagnostic errors detected.	Few diagnostic errors detected; no significant differences among sites; Tissue-specific reviews yielded higher error rates than random reviews.	Tissue-specific reviews yielded higher error rates than random reviews.	2b	2
Raab *et al*[25] (2006)	Before/after with expert pathologists	Second reading of pathology cases. Random review of 5% of cases and focused review of all cases.	Per cent of diagnostic errors. Impact of difference on patient care.	Focused review detected approximately four times more diagnostic errors than 5% random review. The majority of errors in both groups did not lead to patient harm or resulted in low-grade harm.	Second opinion reviews can be a method to standardise diagnostic practice.	4a	3
Manion *et al*[26] (2008)	Before/after with expert pathologists	Second reading of pathology slides received from an external organisation.	Rate of diagnostic variation and change in patient management due to second reading.	No disagreement in majority; minor disagreement in small %; major disagreement in very small % of cases. Change in management plan in half of cases with major disagreement.	Mandatory second opinion of surgical pathology may be a beneficial patient care practice. However, upon disagreement, it is not clear how often the second opinion was correct due to inconclusive chart reviews.	4a	2
Nordrum *et al*[27] (2004)	Before/after with expert pathologists	Use of still images in second opinion of pathology cases.	Diagnostic accuracy rate (glass slides vs still images).	Nearly the same diagnostic accuracy rate with still images and glass slides.	Using still images to diagnose cases appears to be comparable to using glass slides, thus increasing ease of obtaining second opinions.	3	3

Continued

Table 3 Continued

Author (year)	Study type and participants	Intervention	Outcome measures	Results	Conclusions	Outcomes Rating	Strength of conclusions (1–5)
Hamady *et al*[28] (2005)	Before/after with an expert surgeon, oncologist and pathologist	Use of second opinions of a multidisciplinary team of clinicians.	Percentage of second opinions resulting in different diagnosis.	Complete agreement in majority of cases. Disagreement a small % of the time.	Diagnostic and therapeutic discrepancies can occur when multiple experts review the same patient case. It is unclear if the second opinion leads to better outcomes.	4a	4
			Second opinions in radiology				
Benger and Lyburn[29] (2003)	Before/after with ER and radiology staff	Second reading of radiographs by the radiology staff for x-rays processed by ER.	Rate of diagnostic agreement. Clinical impact of diagnostic discrepancy.	Very small amount of discrepancies that required minuscule change in management.	The low rate of significant misread radiographs suggests incorporation of selective second readings may be warranted.	4a	3
Espinosa and Nolan[30] (2000)	Before/after with ER physicians and radiologists	x-Rays read by ER physician and radiologist.	Radiograph interpretation error and number of potential adverse events.	Interpretation error rate and potential adverse effects decreased (based on reliability model not raw data).	Procedures for interpreting radiographs designed to mitigate errors can reduce the adverse events. Without a control group it is difficult to know if improvement is from intervention.	4a	2
Duijm *et al*[31] (2007)	Before/after with mammography technicians and radiologists	Second reading of mammograms by technologists, along with standard double reading by radiologists.	Breast cancer detection and positive predictive value (PPV) of referral.	Modest increase in cancer detection and modest decrease in PPV.	Adding second reading by technologists may be effective in detecting more breast cancer cases. Readings should be considered for referral due to high prevalence of breast cancer.	4a	4

Continued

Table 3 Continued

Author (year)	Study type and participants	Intervention	Outcome measures	Results	Conclusions	Outcomes Rating	Strength of conclusions (1–5)
Kwek *et al*[82] (2003)	Before/after with expert pathologists	Blinded second readings in mammography.	Rate of cancer detection, patient recall, rate of biopsy and mean second screener contribution.	Low increase of cancer detection. Recall rate increased modestly. Biopsy rate slightly increased. Efficiency of second reader minimal.	Second reading of mammograms is recommended for breast cancer screening if resources are available.	4a	4
Canon *et al*[83] (2003)	Before/after with expert radiologists	Second review of barium enema tests.	Detection of polyps.	Second reading failed to improve detection of polyps.	Routine second reading is not warranted for barium enema examination.	4a	4
			Help from groups and librarians				
Christensen *et al*[84] (2000)	Non-randomised controlled trial with clinical teams	Team diagnostic decision-making where members were given shared or private information that the group needed to share for correct diagnoses.	Diagnostic error rate.	Diagnostic errors increased when team members held private information.	Lack of sharing data may be detrimental to diagnostic accuracy. Clinical decisions relying on privately held information are susceptible to errors.	2b	4
Mulvaney *et al*[85] (2008)	Randomised control trial with clinical teams	Use of evidence based informatics tool that provides research evidence to inform clinicians of patient care practices.	Impact on patient care practices and clinical actions, articles read, satisfaction of search results, consultations, time to obtain evidence, clinician searches.	Tool had significant impact on users' report of future patient care, satisfaction of articles returned and amount of time spent receiving evidence. No significant impact on other items.	Informatics tools may facilitate use of research evidence and influence clinical actions. However, data regarding effects on patients are unknown as a result of this study.	3	4

Outcome Ratings reflect the level of impact for each intervention on reducing diagnostic errors.[9 10] Strength of Conclusions was rated on a numerical scale (1–5) in accordance with Best Evidence in Medical Education guidelines (5=strongest).[9 11] ER; Emergency Room.

Table 4 Interventions: help from decision support

Author (year)	Study type and participants	Intervention	Outcome measures	Results	Conclusions	Outcomes Rating	Strength of Conclusions (1–5)
Focused decision support using decision support tools on a specific condition							
Pozen *et al*[36] (1984)	Non-randomised control trial with ER physicians	Incorporation of decision support tool that calculates the probability of patient having ischaemic heart disease.	Diagnostic accuracy, sensitivity, specificity, FP diagnosis rate, FN diagnosis rate, CCU admission rate, ER discharge rate.	Use of tool increased diagnostic accuracy and specificity; sensitivity remained unchanged. FPs and CCU admissions decreased. FNs remained unchanged.	Use of tool has potential to increase diagnostic accuracy and reduce admission rate.	4b	4
Selker *et al*[37] (1998)	Non-randomised control trial with attending ER physician and residents	Computerised prediction tool that calculated probability of acute ischaemia that was printed on ECG.	Accuracy of triage decisions.	Tool reduced unnecessary CCU admissions and did not change appropriate admission rates.	Use of the tool has the potential to significantly reduce unnecessary hospitalisations.	4b	4
Bogusevicius *et al*[38] (2002)	Randomised control trial with radiologists	Use of a computer-aided diagnosis tool to diagnose acute small bowel obstruction.	Specificity, sensitivity, FP predictive value, FN predictive value, time to diagnose, mortality and morbidity.	No significant advantage over contrast radiography for diagnostic accuracy. Significantly less time required to diagnosis.	Computer-aided diagnosis improved amount of time to diagnose, but no other indices.	4b	3
De Simone *et al*[39] (2007)	Before/after with medical personnel	Use of computer-assisted diagnosis database for diagnosis and patient management of headaches compared with standard clinical method.	Diagnostic accuracy, mean visit duration, operators' subjective opinion of tool user friendliness, patients' subjective opinion of computer-assisted interview acceptability.	Slight increase in diagnostic accuracy. Duration of clinical visit comparable. Subjects felt tool was easy to use and patients felt the tool use was acceptable.	The tool improves diagnostic accuracy without increasing visit duration.	4a	3

Continued

Table 4 Continued

Author (year)	Study type and participants	Intervention	Outcome measures	Results	Conclusions	Outcomes Rating	Strength of Conclusions (1–5)
Focused decision support using embedded decision support tools (Infobuttons)							
Cimino[40] (2006)	Survey with nurses, attendings, residents, medical students	Use of online resources through an Infobutton Manager (IM) providing direct, context-specific information.	User satisfaction regarding information returned from online resources.	Satisfaction with the IM varied. Overall users felt IM had a positive effect on patient care decisions.	Context-specific access to health knowledge resources can be seen as useful. More research is needed on the impact on patient outcomes.	1	3
General decision support using web-enabled differential diagnosis generators							
Ramnarayan *et al*[41] (2006)	Before/after with paediatric interns and residents	Use of an internet diagnostic decision support tool (ISABEL) during diagnosis.	Change in proportion of unsafe diagnostic investigations and mean quality score of diagnosis following tool consultation.	Significant proportion of unsafe investigations reduced with tool use. Mean diagnostic quality score increased.	Use of stand-alone diagnostic system to improve diagnostic decision-making for junior physicians is beneficial. However, several barriers must be overcome in order for such tools to be most effective.	3	3
Ramnarayan *et al*[42] (2007)	Audit of system	Use of diagnostic decision support tool (ISABEL) when diagnosing patients with resuscitation issues in emergency room.	Percentage of time accurate diagnosis was in list provided by tool and proportion of time tool included must-not-miss diagnoses.	Tool contained correct diagnosis and must-not-miss diagnosis in nearly every case.	Diagnostic aid performs an acceptable degree of clinical accuracy in ED. Further research is needed to determine role of tool in clinical practice.	2b	3
Ramnarayan *et al*[43] (2003)	Audit with clinicians of varying levels of expertise and system	Use of internet diagnostic decision support tool (ISABEL) as a reminder of possible diagnoses to consider.	Proportion of cases with expected diagnosis in results generated by tool.	Using hypothetical and real patient cases, tool returned the correct diagnosis in nearly every case.	Tool showed acceptable clinical accuracy by providing correct diagnosis for real and hypothetical cases. It is anticipated the use of tool is effective in assisting physicians to accurately diagnose children.	2b	4

Continued

Table 4 Continued

Author (year)	Study type and participants	Intervention	Outcome measures	Results	Conclusions	Outcomes Rating	Strength of Conclusions (1–5)
Ramnarayan *et al*[44] (2006)	Before/after with clinicians of varying levels of expertise	Use of a diagnostic system (ISABEL) to determine diagnosis after diagnosing case without system.	Rate of diagnostic errors, diagnostic quality score and time using system.	Decline in diagnostic errors. Increase in diagnostic quality score. No significant outcome by level of experience. Median time for system use was 1 min.	Study suggests promising role for reminder-based diagnostic decision support tool to reduce diagnostic errors.	4b	4
Graber and Matthew[45] (2008)	Before/after with physicians and system	Use of diagnostic decision support tool (ISABEL) to determine correct diagnosis upon entry of patient key findings of complex medical cases.	Percentage of cases where tool returned the same diagnosis as listed in the NEJM. Amount of time using the tool.	When entering evidence manually tool returned correct diagnosis in nearly all cases. When pasting case text as listed in NEJM, tool contained correct diagnosis three-fourths of cases. Both entry approaches were fast.	Tool performed quickly and accurately in suggesting correct diagnoses and should be evaluated in natural environments to determine its potential to support clinical diagnosis and reduce the rate of diagnostic errors.	2b	3
Tang and Ng[46] (2006)	Audit with physician and rheumatologist	Searching Google.com to determine correct diagnosis for case presented in NEJM.	Percentage of diagnoses from Google that corresponded with NEJM diagnosis.	Google searches revealed correct diagnosis in slightly more than half of cases.	As the internet becomes more available in clinical settings, use of web-based searching tools may help physicians diagnose difficult cases.	2b	2

Outcome Ratings reflect the level of impact for each intervention on reducing diagnostic errors.[9 10] Strength of Conclusions was rated on a numerical scale (1–5) in accordance with Best Evidence in Medical Education guidelines (5=strongest).[9 11] CCU, Coronary-care unit; ER, Emergency Room; FN, False Nagetive; FP, False Positive; NEJM, New England Journal of Medicine.

additional training in cancer detection where they attend disease-related meetings, receive feedback on cancer detection rates and attend a 2-week course led by specialists at high-volume mammography screening sites.[55] Similar measures, including regular peer review and participation in the American College of Radiology's RADPEER™ system, have been proposed for the USA.[148]

Interventions to increase the knowledge base of practicing clinicians through continuing medical education activities have generally not led to substantial improvement in measured performance.[56 57]

Table 5 Intervention suggestions

Intervention idea	Suggested in article authored by
INCREASE MEDICAL KNOWLEDGE AND EXPERIENCE	
General	
Increase expertise and experience	Kassirer *et al*[47]; Gigerenzer[48]; Elstein[49]; Klein[50 51]; Berner and Graber[1]; Bazerman and Moore[52]; Norman[53]
Training	
Routinely test competency in diagnostic accuracy; provide training to increase competency	Smith-Bindman *et al*[54]; Singh *et al*[55]
Continuing education	Bowen[56]; Davis *et al*[57]
Focused training on specific content area	Freidlander and Phillips[58]; Gentner[59]; Hershberger *et al*[60]; Parmley[61]
Improve learning skills, per se	Hogarth[62]
Simulation	
Develop simulation exercises to expose clinicians to a greater number and variety of case presentations	Bond *et al*[63]
Feedback and calibration	
Provide intensive, detailed, specific feedback	Smith-Bindman *et al*[54]; Schiff[64]; Jamtvedt *et al*[65]; Papa *et al*[66]; Stone and Opel[67]; Alpert and Hillman[68]; Arkes[69]; Humble *et al*[70]; Pulford and Colman[71]; Subbotin[72]
Learn from errors	Fischer *et al*[73]; Hogarth[62]; Eva[74]
IMPROVE INTUITIVE AND DELIBERATE PROCESSES IN DECISION-MAKING	
General	
Improve general training on clinical reasoning & the dual process model	Berner and Graber[1]; Kassirer *et al*[47]; Elstein[49]; Eva[74 75]; Croskerry[76–78]; Norman[53]; Wolpaw *et al*[23]
Improve system 1 processing	
Improve training on intuitive processing and its shortcomings	Berner and Graber[1]; Croskerry[76–78]; Wedding and Faust[79] Groves *et al*[80]; Pines[81]; Moulton *et al*[82], Trowbridge[83]; Kuhn[84]
Debias your own intuitive decisions	Croskerry [76–78]; Norman[53]; Fischhoff[85]; Milkman[86] Larrick[87]; Gentner *et al*[59]; Koriat *et al*[88]; Renner and Renner[89]; Estrada *et al*[90] Scott[91]; Slovic and Fischoff[92] Arkes *et al*[69 154]; Lichtenstein *et al*[93]
Improve metacognition, nurture intuition and use of reflective practice	Schon[94]; Greenhalgh[95]; Mamede *et al*[96]; Singh *et al*[97]; Brawn[98]; Gregory[99]; Noddings and Shore[100]; Quirk[101]; Klein[51]; Hogarth[62]; Hamm and Zubialde[102]; Moulton *et al*[82]; Trowbridge[83]; Croskerry[76–78 103]
Use a checklist or related tools	Leonidas[104]; Gawande[105]; Trowbridge[83]; Ely *et al*[106]
Consider alternatives; consider the opposite; use prospective hindsight; think like an outsider	Taleb[107]; Wedding and Faust[79]; Sackett *et al*[158]; Brannick *et al*[108]; Milkman *et al*[86]; Arkes[109]; Croskerry[78]; Schwenk[110]; Baron[111]; Mitchell *et al*[112]; Bazerman and Moore[86]; Mussweiler[113]; Lord *et al*[114]; Arzy *et al*[115]; Gorman and Gorman[116]; Hirt and Markman[117]; Mumma and Steven[118]; Singh[97]

Continued

Table 5 Continued

Intervention idea	Suggested in article authored by
Improve system 2 processing	
Teach principles of clinical reasoning; use evidence-based medicine and normative decision-making	Wedding and Faust[79]; Strauss *et al*[119]; Sox[120]; Dobbie *et al*[121]; Khan and Coomarasamy[122]; Croskerry[123]; Pines[81]; Ullman[124]; Pauker and Kassirer[125]; Kassirer[126]; Brannick *et al*[108]
Provide training on the typical pitfalls of specific clinical conditions & situations	Groves *et al*[80]; Croskerry[78]; Pines[81]
GET HELP FROM OTHER PEOPLE AND/OR DECISION SUPPORT TOOLS	
Second opinions	
Use specialist consultants & second opinions; improve team-based decisions, for example, by having a devil's advocate	Elstein[49]; Christensen *et al*[84]; Tatarka[127]
Second readings in pathology	Ullman[124]; Raab[128]
Groups and librarians	
Get help from groups or librarians	Zipperer and Sykes[129]; Albert[130]; Zipperer[131]
Actuarial decisions	
Use of guidelines, clinical algorithms, linear models and mnemonics to reduce reliance on memory	Elstein[49]; Croskerry[78]; Berner and Graber[1]; Tatarka[127]; Milkman *et al*[86]; Wedding and Faust[79]; Wedding[132]; Fischhoff[85]
Focused decision support	
Decision support tool on a specific condition	Hunt *et al*[133]; Klassen *et al*[134]; Garg *et al*[135]; Cannon and Allen[136]
Improve data display through graphics	Radecki and Medow[137]; Reyna *et al*[138]; Bhandari *et al*[139]; Cook and Smallman[140]
Embedded decision support tools; Infobuttons	Kawamoto and Loback[141]
General decision support	
Improve medical records	Hamm and Zubialde[102]; Schiff and Bates[142]

Interventions

We identified three formal studies of training interventions related to diagnostic error.[12–14] One notable study was a highly content-specific intervention to improve recognition of subarachnoid haemorrhage. This low-cost training programme on sudden onset headache for community-based physicians reduced the baseline diagnostic error rate (12%) by 77% and improved interactions between neurosurgeons and local physicians.[12]

Simulation

The ability to provide realistic simulations through both scenarios and simulated patients offers the potential to improve skills in clinical reasoning[63] and the opportunity to expose trainees or physicians to a greater number and variety of case presentations. Simulation is a well-established approach to improving manual, procedural skills, but has not yet been evaluated extensively in its ability to improve cognitive skills or decision-making related to diagnosis. It also remains to be demonstrated that simulation can replace experience in actual practice.

Interventions

We identified only two interventions in this domain, both involving trainees. Carlson *et al*[16] demonstrated improved diagnostic accuracy by the combined use of simulation with a diagnosis support tool and Bond *et al*[15] used simulation successfully to introduce the use of cognitive forcing strategies to emergency medicine residents.

Feedback as a way to improve expertise, calibration and error awareness

Deliberate practice, with immediate and focused feedback, is viewed as an essential prerequisite to developing expertise in any domain.[144 145] Moreover, lack of feedback is a dominant factor that sustains overconfidence, thought to be a major factor in causing diagnostic error.[1] A systematic review of feedback across all medical areas (not solely diagnosis) concluded that feedback improves performance in selected settings, especially if the feedback is intensive.[65] Feedback is most useful if it incorporates instruction and information on why a given answer was correct or not.[66 67] For example, psychology trainees improved their diagnoses if feedback provided

details on why they were right or wrong.[18 149] Using feedback to improve diagnostic performance has been most convincingly demonstrated in radiology through programmes such as the 'PERFORMS' system in the UK[54] and the RADPEER programme in the USA.

Although clinicians received immediate and dramatic feedback on their diagnostic performance from autopsies, the rate of autopsies is declining.[150] Local 'Morbidity and Mortality' conferences[73] and creative new venues such as the 'Web M&M' series sponsored by the Agency for Healthcare Research and Quality (http://www.webmm.ahrq.gov/) are alternative venues where feedback is provided.[151] In this spirit, Eva[74] has advocated for incorporating diagnostic error review into medical school and postgraduate training. Alpert and Hillman discuss other types of data that should be part of such feedback, such as the results of professional audits, peer reviews and risk management programmes.[68]

Interventions

Our search yielded two studies on feedback to improve diagnostic performance.[17 18] Both studies showed benefits of feedback on later diagnostic accuracy. The positive impact noted by Wood and Tracey[18] was possibly explained by the provision of detailed feedback to trainees on the reasons their initial diagnoses were correct or not.

Category 1 summary

The empiric studies identified were positive, but generally used trainees and specific content limiting the ability to generalise the impact of results to actual practice.

2) Improve clinical reasoning

According to the currently popular paradigm, diagnoses are made by some interacting combination of intuitive, automatic processing (system 1) and deliberate, rational consideration (system 2).[152] Interventions to reduce diagnostic error have been suggested in each of these areas, and many authors have advocated for the benefits of general training in clinical reasoning.[1 23 47 49 53 75–78] The interventions in this domain are presented in table 2.

Improve intuitive processing: debiasing

Many, and perhaps most, medical diagnoses are derived intuitively, acknowledging that most conditions are common and present in typical, easily recognised, fashion. Coderre *et al*[153] found that intuitive diagnoses are more likely to be correct compared with diagnoses derived by hypothetico-deductive reasoning, and this concept is also consistent with the substantial literature regarding expertise.

Experts in the field of naturalistic decision-making emphasise that intuitive judgements cannot be taught because they emerge subconsciously from the amassed experience of the decision-maker and his or her ability to access this knowledge instantaneously and effectively.[48 50] However, others have argued that intuition *can* be encouraged, strengthened and improved.[51 101 151] Brawn highlighted several strategies to encourage use of intuition such as showcasing examples of how intuition was used in discovery and insight situations.[98] Noddings and Shore[100] suggest that intuition can be developed by first acknowledging intuition and its role in decision-making, demonstrating its capacity and successes, and by sharing how intuition is used, especially by experienced role models. Hogarth[151] recommends a series of novel educational interventions to teach and improve intuition, including creating increased motivation to learn by exposure to one's own errors and constantly seeking to improve one's learning skills by reviewing and revising skills in observation, sense-making and hypothesis testing.

Croskerry and others have argued that clinicians would make fewer errors if they learned the potential shortcomings (biases) of intuitive decision-making so as to understand and avoid them.[76 77 91] Interventions to avoid both affective bias (engendered by our inherent discomfort with certain types of patients or interactions) and cognitive bias (due to the known shortcomings and pitfalls of subconscious thought) have been suggested.

Similar debiasing interventions were suggested by Fischhoff[85] and included: (1) warning about the possibility of bias; (2) describing how the bias distorts good decisions; (3) letting the individual make a bias-related judgement error and giving them feedback; and (4) repeating these cycles with extended coaching. Larrick[87] reported an example of successful debiasing by keeping it focused on a particular context and a particular bias.

Experimental evidence suggests that hindsight bias can be reduced by considering alternatives.[154] In one such study, subjects were asked to choose between two answers to a difficult question,[93] where some were asked to give the reasons they made their choice and others were asked to give reasons both for and against their choice. Considering both alternatives improved accuracy and reduced the tendency for subjects to be overconfident in their answers.[92] Similarly, physicians evaluating a difficult test case were more likely to trust a diagnosis when asked to consider alternatives.[154]

Although debiasing is potentially attractive, several authors have expressed scepticism if this approach will work based on the intrinsic difficulty of changing the subconscious processing individuals use in decision-making.[86 155 156]

Interventions

Our search yielded two studies. Sherbino and colleagues[19] tested an effort to improve clinical reasoning of trainees by teaching them cognitive forcing strategies to counteract biases. The study lacked baseline data (no measure prior to intervention) or a control group, and the results were generally negative. In addition, the reported retention of the cognitive forcing strategies that were the subject of the intervention was short-lived. Eva *et al* encouraged the use of combined strategies (pattern recognition plus deliberate consideration) in teaching students to read electrocardiograms (ECR), and found this improved their diagnostic performance in part by avoiding biases.[20]

Improving metacognition and reflection

Improving metacognition, the ability to reflect on one's own thought processes, is an appealing approach to reduce cognitive error.[77 78 103] Metacognition could potentially alert clinicians to possible flaws in their reasoning and help detect errors. A related and widely endorsed recommendation is to practice reflectively,[82 94 96 97 102] recently referred to as the diagnostic 'time out'.[83] Reflective practice promotes metacognition and incorporates four distinct elements: Seeking out alternative explanations, exploring the consequences of alternative diagnoses, being open to tests that would differentiate the various possibilities and accepting uncertainty. This process, essentially getting a second opinion from your own conscious mind, has the potential to avoid many of the inherent pitfalls of heuristic thought.[82]

Several tools have been suggested that might be helpful to promote metacognition and reflective practice, including Trowbridge's '12 Tips' and Leonidas' 'Ten Commandments'.[83 157] Using a diagnosis checklist, by promoting conscious review and reflection, has also been advocated as a way to avoid pitfalls in clinical reasoning.[106 157]

Interventions

Two studies were identified. Mamede and colleagues found that conscious reflection decreased the tendency towards availability bias,[21] and Coderre *et al* demonstrated that reflection on an initial diagnosis was helpful if the initial diagnosis was wrong, and did not lead to new errors if the initial diagnosis was correct.[22] A limitation of both studies is that the additional time spent on problem solving may be what is driving the result, not conscious reflection per se. Also, both studies involved trainees in a laboratory environment, so that the positive results would have to be reconfirmed in practice settings. It is therefore inconclusive whether these techniques successfully reduce diagnostic errors.

Consider alternatives

A central element of reflective practice is reviewing alternative diagnoses, an approach widely endorsed as a valid approach to improved decision-making[107] which we consider separately in this section. In this approach, clinicians should invoke what has been called the universal antidote, 'Could this be something else?' and use appropriate tests to exclude the alternatives, rather than ordering tests that simply confirm original suspicions.[107] Others[79] have also suggested that clinicians 'jot down, in advance, outcomes that would support one's initial conclusions and also those that would disconfirm them' or consider alternatives.[111] A related strategy is to assume the perspective of an outside observer,[86] prompting evaluation of the decision-making strategy that was used and whether or not it was flawed. Military planners have used 'prospective hindsight' to teach this principle: one looks into the future to see that the working diagnosis is not correct: What was missed and what else should have been considered?[97 112]

Interventions

Our search yielded one study that tested an intervention in this category. Wolpaw *et al*[23] attempted to improve clinical reasoning and decision-making skills through a six-step training programme for medical students to express their diagnostic reasoning process. The impact of this technique on diagnostic errors is inconclusive since the study did not assess the reduction of diagnostic errors, but only assessed frequency and thoroughness of their skills in presenting a patient case. The study only measured the presence/amount of reasoning and not accuracy thereof, and so it is unclear how this intervention would improve diagnostic accuracy.

Improve rational processing

Rational, deliberate review and consideration combine the use of evidence-based knowledge[158 159] with two normative approaches, the use of expected value decision-making[160] to choose among a group of possible diagnoses and Bayesian analysis to incorporate test results in considering a single diagnosis. Kassirer *et al*[47] describes the process of clinical reasoning as generating initial hypothesis which are then investigated by diagnostic tests and Bayesian analysis until an appropriate threshold (Treat, Don't Treat) is reached. Kassirer suggests that the essential skills of clinical reasoning can and should be taught to medical students from their first days,[126] and reviewers have concluded that conscious review can be taught effectively.[121 122] Trainees taught

principles of evidence-based medicine are more likely to use Bayesian techniques to interpret clinical findings.[158] In efforts to reduce surgical cognitive errors, Brannick *et al*[108] oriented surgical trainees to Reason's major error types using an educational video and role-playing emphasising errors. Although actual surgical error rates were the same as in untrained controls after a month, attention to detail improved.[108]

Category 2 summary

We noted a major discrepancy between the breadth and enthusiasm for these interventions in the background studies, but a paucity of actual interventions. For all three categories, there is very limited evidence addressing diagnostic accuracy or errors. The studies identified involved trainees in laboratory-like settings, limiting the ability to generalise the findings to real practice.

3) Get help: use other people and decision support tools

Given the constraints of human cognition,[78] physicians may be able to augment their innate cognitive abilities by obtaining advice and help from others. All of the tested interventions in this category are detailed together in online appendix C and were organised in the following categories.

Second opinions

Interventions

Several studies have demonstrated that second reviews of surgical pathology or cytology specimens find a small but important group of errors,[24–28] and a growing number of healthcare systems now require second readings in case types known to have substantial rates of inter-observer variability. Most of these studies do not, however, include data on patient outcomes (table 3).

Second readings in radiology also improve test sensitivity. Duijm *et al*[31] found that multiple independent readers (radiologists or technicians) increased cancer detection rates with only a slight decrease in specificity, and Kwek *et al*[32] found that second reading increased cancer detection by 5%.

The impact of second readings has been mixed in other settings. Second reading of Emergency Room (ER) imaging studies was helpful in one study,[30] but in another, besides identifying previously missed abnormalities, the second reading introduced new misinterpretations leading to inappropriate changes in management.[29] Canon *et al*[33] measured the impact of independent double reading of barium enemas and found no effect on the sensitivity of polyp detection and an increased rate of false positives.

Thus, the overall impact of 'second opinions' on diagnostic errors appears to be mixed. Sensitivity appears to improve in most but not all studies, but the second readings tend to introduce new errors that detract from the specificity of the diagnostic test. Results could potentially be both reliable and generalisable because of the relatively large number of cases reviewed in these studies, and the use of expert reviewers. Cost–benefit analyses will be needed to determine whether the costs of second readings and the seemingly inevitable increment in false positives are offset by the increased rate of case finding.

Groups and librarians

Groups can make better decisions than its individual members if the members are allowed to function independently.[86 161] Diagnosing challenging cases within teams or with peers would take advantage of this strategy. A recent novel approach leverages the use of librarians who are experienced and skilled in identifying information, evidence, and knowledge relevant to diagnostic alternatives or testing strategies.[129–131]

Interventions

One study by Christensen *et al*[34] studied team-based decisions. This was a well designed, controlled study, but the results were negative: performance did not improve by using the team.

A randomised trial of embedded clinical informaticians at one university demonstrated a positive impact on the clinical care provided,[35] although self-reported perceptions were used in place of actual outcomes.

Decision support

Most studies of decision support tools have evaluated impact on process measures, user satisfaction and utility in a limited sense,[141] and are not consistently positive. A systematic review of decision support systems in 1998 identified only a single study focusing on diagnosis,[133] and in this study, using a decision support tool in an emergency room on patients with joint or bone injuries actually led to more missed fractures.[134]

Using linear prediction models (actuarial decision-making, algorithms) has been shown to yield better 'decisions' than most decision-makers, including experts, in a wide range of settings.[111] Wedding and colleagues[79 132 162] report that actuarial diagnosis was more accurate than clinical judgement in patients with neuropsychiatric conditions. However, clinicians tend to disregard advice from these tools or not use them even when they are readily available.[163 164] The importance of embedding decision support in the physician's workflow has been repeatedly emphasised, for example, by incorporating decision support logic in computer-based order entry systems. A systematic review of this approach identified 11 controlled trials, seven of which reported improved professional practice[141] on ordering diagnostic tests.

Hamm and Zubialde and more recently Schiff and Bates have called attention to many other ways in which the electronic medical record can enhance clinical reasoning.[102 142] Besides providing clear access to the necessary data, good records help clinicians organise their thoughts, enhance collaborative thinking, enhance efficiency and promote feedback. Another promising type of clinical decision support enabled by electronic records is the graphic display of timeline data to assist in the interpretation of diagnostic test results and to help detect subtle trends.[137]

Interventions

A recent review identified 10 newer studies, each focused on a specific clinical condition[135] and of these only four studies had positive results: one reported improved ability to detect and diagnose mood disorders in outpatients,[136] two improved diagnosis in acute coronary syndromes[36 37] and one evaluated diagnosis of acute abdominal conditions on a surgical service, which improved provider performance but not patient outcomes[38] (table 4). Finally, De Simone *et al*[39] describe a system that receives clinical information from the patient directly and synthesises that information to aid the clinician in diagnosing the cause of headaches. Overall, the studies were all sound and results seem to be generalisable by virtue of testing a range of subjects and case types.

Another approach to supporting the diagnosis of specific conditions in general is the Infobutton functionality, described by Cimino.[40] The only available study of Infobuttons included subjects from varying levels (attending physicians, residents, medical students, nurses) who were mostly satisfied with the tool. The impact of the tool on diagnostic accuracy and patient outcomes was not assessed.

Computer-aided detection systems

Interventions

Five studies have examined the use of computer-aided detection systems to aid radiologic diagnosis. Peldschus *et al*[165] studied the effectiveness of an automated computer-aided detection system for chest CT studies and found both new positives and false positives. Berbaum *et al*[166] found that use of a computer-aided detection system in chest radiography could not counteract the satisfaction-of-search effect (being able to find additional defects beyond the first one) in 16 subjects. In another study, Kakeda *et al* demonstrated a significant beneficial effect of using computer-aided diagnosis support to help analyse chest radiographs.[167]

In mammography, Jiang *et al*[168] found that computer-aided diagnosis reduced inter-observer variability, but in another study computer-assisted mammography interpretation had no beneficial effects on cancer detection and significantly increased the false positive rate of the studies and the biopsy rate.[169] A recent commentary on computer-assisted detection noted that while use of this technology is increasingly the norm, the jury is still out on its utility.[170] All of the intervention studies reviewed were solid in design and in the interpretation of the results and conclusions, but the ability to generalise is limited due to studies in just two domains (chest x-rays and mammograms).

Computer-aided interpretation systems

Interventions

Two studies focused on technology to improve ECG interpretation. Daudelin and Selker[171] reported using an ECG-based acute cardiac ischaemia predictive instrument to improve triage decision-making in the ER. Olsson *et al*[172] studied the use of an artificial neural network trained to automatically detect ECGs indicating possible transmural ischaemia and found that this decision support tool was effective in improving inexperienced interns' interpretation of ECGs.

General decision support tools for medical diagnosis

Computer aided decision support tools have also been developed to assist specifically with differential diagnosis. Anecdotally these tools succeed, in a small fraction of searches, in suggesting a difficult or obscure diagnosis that was previously missed. The clinician inputs the patient's key findings, and these programmes suggest possible diagnoses. Some programmes help refine these choices by further suggestions of questions to ask, findings to look for or tests to perform. Berner *et al* evaluated the first generation products (QMR, DXplain, Iliad and Meditel) using test scenarios and all the products were effective in providing useful suggestions.[173] However, the correct diagnosis appeared on the suggestion list only half to three-fourths of the time, and all of the programmes generated a large number of extraneous conditions.[174] Some of these initial products are no longer available, although DXplain has been maintained and updated.

Interventions

Of the many newer web-based decision support tools, 'ISABEL' has been the most extensively evaluated. Compared with first generation tools, ISABEL displays much improved sensitivity in both paediatric settings[41 42] and in analysing adult case scenarios, in which the sensitivity approached 100%.[43–45] 'Google' searching has also been evaluated in medical settings, but suggests the correct diagnosis in only 58% of difficult cases.[46]

Category 3 summary

Overall, the technique of 'getting help' during the diagnostic process may be beneficial. The use of decision support resources has been studied more extensively

than any other intervention, and these approaches, if used, show promise in their potential to reduce diagnostic errors. More research is needed regarding the use of second reviews, teams and librarians.

DISCUSSION

Reducing harm from diagnostic errors requires interventions to improve the cognitive processes that underlie clinical reasoning. We identified a reasonably large literature on potential interventions and organised these interventions into three categories: (1) Increasing knowledge and expertise, (2) Improving intuitive and deliberate consideration and (3) Getting help from colleagues, consultants and tools.

We found that most interventions in the literature were simply ideas or suggestions. Many of these are well conceptualised and widely endorsed, and seem ripe to be tested in experimental or real-world clinical settings. A major finding in each of the three categories was a large discrepancy between the broad and enthusiastic recommendations for the various interventions, but a relative paucity of actual trials. Of the few studies that reported true interventions, few included robust designs or metrics. Typically, the interventions involved an observational study design and measured outcomes before and after an intervention with a small number of trainees or clinicians and/or healthcare sites, without a control group.

Our findings also affirm that the science of outcome measurement in this area is underdeveloped. Educational interventions in particular are difficult to evaluate in terms of changing attitudes and behaviours in practice. One major issue is the difficulty of demonstrating that diagnosis can be improved by *any* approach in real-world settings. Definitions of diagnostic error are not standardised and error designations are typically subjective judgements, often confounded by hindsight bias. Measurement instruments and methods to evaluate cognitive intervention effects are not well developed. Additionally, because diagnostic error reflects the interplay of system-related and patient-dependent factors, the true effect of a purely cognitive intervention might be difficult to ascertain. All of these factors pose challenges in the design of future interventions in this area.

The major limitation of this review is the likelihood that we overlooked conceptual ideas to improve decision-making from both medical and non-medical fields. Medical diagnosis is essentially a special case of decision-making under conditions of uncertainty, and ideas for improving these decisions can arise from almost any discipline, including the social sciences, business fields and military scholars.

A clear challenge going forward is to identify the advances in these areas that might be applicable to improving the reliability of medical diagnosis. Despite the many shortcomings of these studies, our review identified promising ideas for reducing diagnostic error in each of the three major categories.

Increase knowledge

At the present time, disease-specific training is the only intervention that is both supported by evidence and seems implementable. In the future, simulation offers potential both in terms of teaching clinicians about diagnostic error and error-prevention strategies, as well as serving as a method to rapidly build expertise through exposure to many types of disease variants. Feedback also offers the potential to reduce errors by helping develop expertise. Feedback is also the key to reducing overconfidence, which in turn could open the door for clinicians to appreciate the possibility of their own errors and take actions to avoid them. Deliberate feedback is embedded in many approaches that seek to improve individual and team performance outside of medicine.

Improve clinical reasoning

Although some of the interventions to improve reasoning have been successful with trainees, most have yet to be implemented or evaluated in practice. Reflective practice and active metacognitive review may have great potential to reduce diagnostic error, and the tools to promote these practices need to be further developed and evaluated in practice. These approaches expand the number of conditions to be considered and effectively address many of the major causes of cognitive error, including context errors, framing bias and premature closure. However, the cost of trade-offs is not clear. For example, will the broadened consideration of alternative diagnoses lead to inappropriate or costly testing, divert attention away from the correct diagnosis or be deleterious in another way?

Get help

Decision support for diagnosis has the unique advantage that it can be implemented at the system level, without requiring some new skill or behaviour to be learnt by clinicians. Still, clinicians need to be willing to take advantage of these resources, and error reduction will critically hinge on how well the support functionality is incorporated into everyday workflow and how clinicians will deal with the specificity problem. Using informaticians, working more effectively in groups, taking full advantage of the comprehensive electronic health record and relying more on actuarial tools (algorithms) may be effective strategies. Second opinions and

consultations bring fresh eyes to examine a case, a powerful and effective way to find and correct diagnostic errors.

CONCLUSIONS

In conclusion, there is a surprisingly wide range of possible approaches to reducing the cognitive contributions to diagnostic error. Not all the suggestions have been tested, and of those that have, the evaluations typically involved trainees in artificial settings, making it difficult to extrapolate the results to actual practice.

The field is immature and progress in reducing diagnostic error will require considerable research to evaluate the relative merits of these different ideas, refinements in the methodology of defining and measuring outcomes in preventing diagnostic error and harm, and leveraging advances in other aspects of medical decision-making and cognitive sciences that may make medical diagnosis more reliable.

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