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ORIGINAL ARTICLE

Artificial Intelligence in Medical Education: A citation-based systematic literature review

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A B S T R A C T

Purpose: This review aims to describe the existing and emerging role of Artificial intelligence (AI) in medical education, as this may help set future directions.

Methodology: Articles on AI in medical education describing integration of AI or machine-learning (ML) in undergraduate medical curricula or structured postgraduate residency programs were extracted from SCOPUS database. The paper followed the guidelines of Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) research methodology. Articles describing AI or ML, but not directly related to teaching and training in structured programs were excluded.

Results: Of the 1020 documents published till October 15, 2020, 218 articles are included in the final analysis. A sharp increase in the number of published articles was observed 2018 onwards. Articles describing surgical skills training, case-based reasoning, physicians' role in the evolving scenario, and the attitudes of medical students towards AI in radiology were cited frequently. Of the 50 top-cited papers, 16 (32%) were 'commentary' articles, 13 (26%) review articles, 13 (26%) articles correlated usefulness of ML and AI with human performance, whereas 8 (16%) assessed the perceptions of students toward the integration of AI in medical practice.

Conclusion: AI should be taught in medical curricula to prepare doctors for tomorrow, and at the same time, could be used for teaching, assessment, and providing feedback in various disciplines.

Keywords: *Artificial Intelligence, Citation Analysis, Medical Education, Systematic Review*

Introduction

Medical practice is evolving rapidly. Increasing ease of access to knowledge, informed patients, societal pressures, and increased litigations have resulted in transformation of clinical medicine practice.[1, 2] In addition to doctors and patients, other healthcare professionals and machines are now play an integral part in the management of patients.[3, 4] The main driver of the evolution of health care over the last few years is digital technology, often referred to as the "Fourth Industrial Revolution (4IR)".[5, 6] Integration of technology in healthcare has been regarded to have the "potential to improve the quality of life for populations around the world".[7, 8]

While AI has brought a revolution in the automotive industry and search engines, it is no longer a futuristic vision for the healthcare industry either.[9] Healthcare industry has traditionally been slow to realize the potential benefits. Despite the slow take-off, AI application in medicine is becoming a topic of keen interest; however, traditional medical education lags behind. Significant reforms, including teaching AI, are needed in medical education to prepare future physicians.[10]

Over the last few years, literature has begun to emerge on the integration of AI in teaching, assessment and

provision of feedback to students. Excellent reviews have been published on the use of simulators,[11, 12] use of gaming techniques for education,[13] and crowdsourcing, to improve health.[14] Masters[15] reviewed the impact of AI on medical educators and its impact on medical education methodology and content. However, only a few bibliographic reviews reported trends of integration of AI.[16, 17] Guimarães, Dourado[16] reviewed advantages of introduction and diversification of pedagogical approaches specifically in anatomy education, whereas Chan and Zary[17] reviewed 37 articles related to the application and challenges of implementing AI in medical education.

The aim of this study were to review the existing data on the integration of AI in medical education, the areas of medical education where the AI is being integrated, the primary uses of AI, and identify areas where AI may be of help. Moreover, the study provides conceptual and social structures using network analysis.

Methodology

A citation-based systematic review of peer-reviewed literature was carried out to identify current patterns of research on the use of AI in structured medical education programs. Relevant articles were searched using the SCOPUS database. SCOPUS is commonly used to carry out citation-based systematic literature reviews.[18-23] There are several advantages of using SCOPUS compared to other databases, such as, Web of Science, ProQuest, as SCOPUS includes the widest range of articles with complete reference sets in a consistent and reliable form.[24]

The initial search was done on October 15, 2020, using the terms “artificial intelligence” OR “machine learning” AND “medical curriculum”, OR “medical student”, OR “medical education”, OR “medical school”, OR “medical college” in the title, abstract, and keywords of all documents.

A total of 1020 documents were retrieved published over a period of 40 years (1979-October 15, 2020). Forty-one articles written in languages other than English were excluded. The search was then restricted to articles published in peer-reviewed journals. At this stage, the title and abstract of the selected documents were skimmed manually to remove irrelevant articles. ‘Relevant’ articles were defined as articles describing integration of AI or ML in undergraduate medical curricula or structured postgraduate residency training programs. Medical education is a continuum of curriculum-based undergraduate medical education, through curriculum and training-based postgraduate programs, to practice-based continuing medical education. Whereas, the former two programs are structured, the latter is opportunistic. Since the aim of the review was to identify what and how much of AI is being integrated into medical curricula, we chose to exclude articles which dealt with practice-based CME programs only. Articles describing AI or ML, but not directly related to teaching and training in structured programs were also excluded. Also, articles related to the use of AI in clinical practice for diagnosis or treatment, nursing practice, continuing medical education, and articles describing the technical aspects of developing AI engines were excluded. Furthermore, articles on the use of technology only, such as, distance learning, e-learning and online learning were also excluded. A second set of analysis was carried out reviewing all abstracts or the whole text, and another 543 articles were excluded. A total of 186 articles were evaluable at this stage.

In order to ensure that relevant articles were not excluded, we compared all cited relevant articles from the reference list of the following studies: Masters (15), Sit, Srinivasan,[25] McCoy, Nagaraj,[26] Briganti and Le Moine,[27] Winkler-Schwartz, Bissonnette,[28] Monlezun, Dart,[29] Bichindaritz and Marling,[30] Lillehaug and Lajoie.[31] Another 32 articles were identified and added to the list. Hence, the final sample consisted of 218 articles published between 1979 and October 15, 2020 in 142 journals.

Mixed-method design of bibliometric analysis and content analysis was carried out. The top 50 most-cited articles were identified using the citation index, defined as number of citations divided by the number of years since published. These articles were reviewed in full to extract information, such as, level of training (undergraduate education versus postgraduate programs, or both), area of study (medical education, radiology, surgery, anesthesia, dermatology etc), publication type (commentary, review article or original study), study design (correlation of AI technique with conventional methods of teaching, or assessment). Finally, the main objectives of the study were identified, and grouped in to 4 main categories.

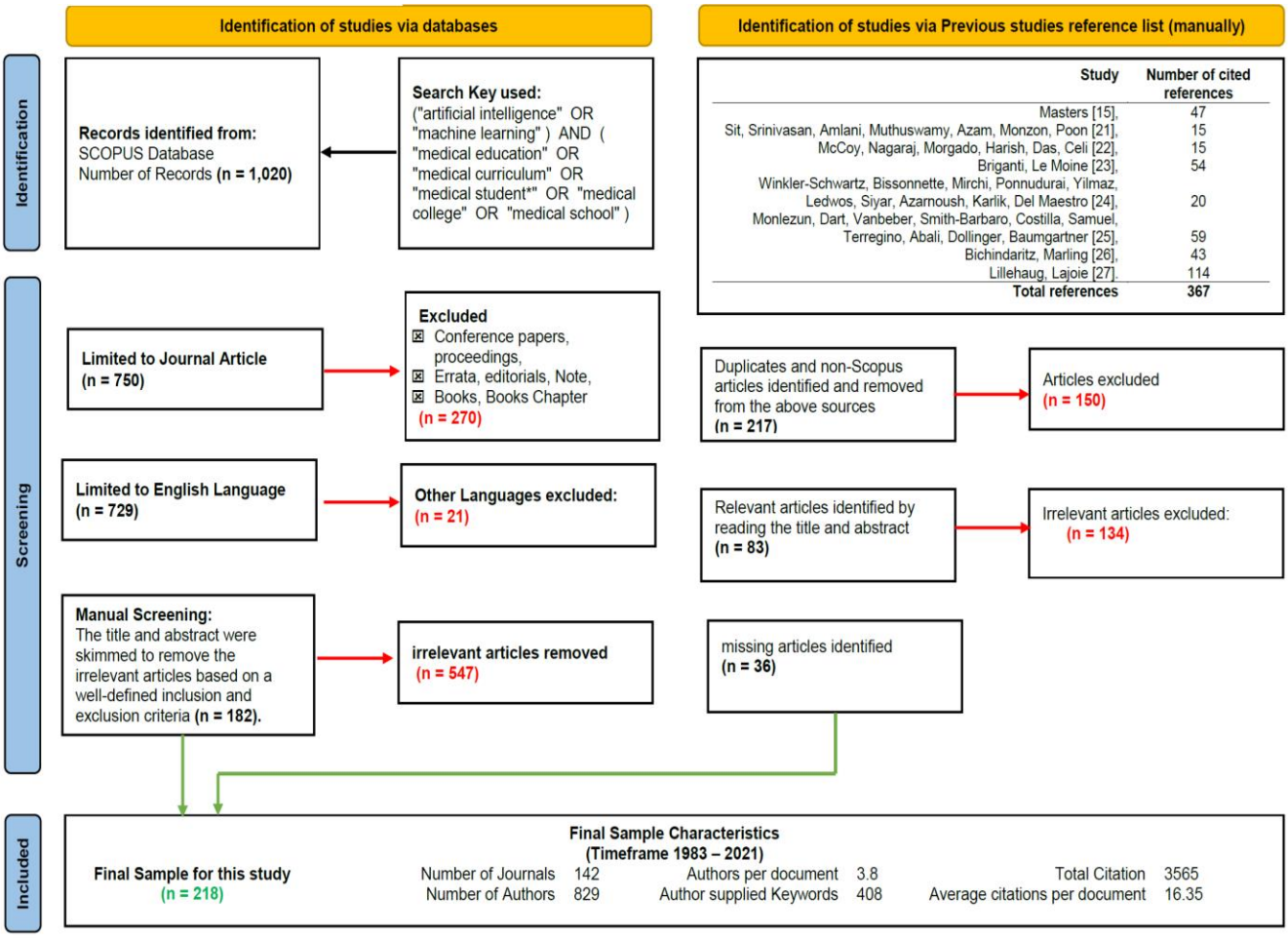


Figure 1: Article Selection Flow Chart (PRISMA)

The data were then plotted over time (number of publications or citations), or analyzed using the Bradford's law, Lotka's law, wordcloud, or the co-word analysis, using "bibliometrix package" developed in "R-language".[18]

Results

The results of the citation and content analysis are presented below:

Publication and Citation Trends

The trends of publication and citations over the study period are shown in figure 2A. A rapid increase in the number of published articles was observed only after 2018, and the number continues to increase.

The data from 2020 are not complete as the literature search was performed on October 15, 2020. The number of citations increased continuously over the years,

the articles on surgical skills training,[32-34] case-based reasoning,[30, 35] role of physicians in the future[36], and the attitudes of students towards AI in radiology[37] were cited more frequently (Figure 2B). The most frequently cited article was that of Gallagher et al published in 2005 reviewing the information on the use of technology to teach minimally invasive surgery. The authors argued for a gradual introduction and integration of virtual reality into education and training program together with skills assessment.

Content Analysis of the most cited papers

Abstract of 50 most-cited articles were identified and reviewed to study the contents. If abstracts were not informative, entire manuscript was reviewed. There were 16 (32%) 'commentary' articles (commentary, perspective, editorial etc.), and 13 (26%) review articles (Figure 3). A total of 13 (26%) articles looked at the usefulness of AI

engines using correlation with human performance, whereas, 8 (16%) articles assessed the awareness or perceptions of medical students or residents toward the integration of ML and AI in medical practice.

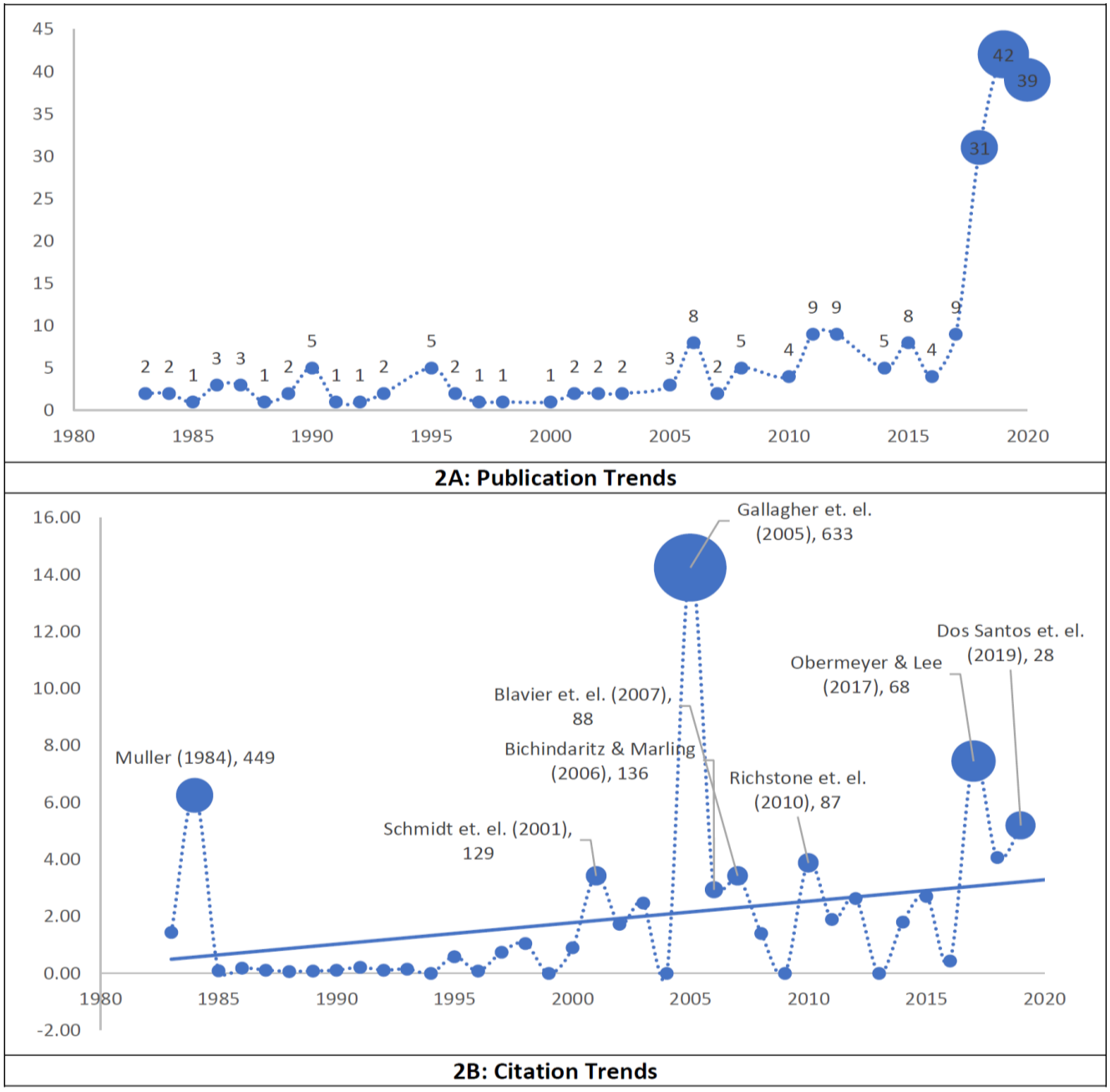


Figure 2: 2A and 2B Publication and Citation Trends

We also studied the scope of studies. Nineteen studies discussed the role of AI in undergraduate studies, 18 in postgraduate and 3 described the role in both. Whereas 19 (38%) studies were related to medical education methods, 11 (22%) and 10 (20%) described the integration of AI in surgery and radiology respectively. Other areas included anatomy, physiology, dental medicine, prescription writing, otorhinolaryngology, anesthesia, acute care and pathology (1-2 studies). A total of 21 (42%) studies were related to teaching, assessment and providing feedback to junior doctors in residency training programs. Overall, the results suggest that there is an increasing recognition to use AI

tools in medical education, surgical and radiology training, however, in some other areas, AI needs to be incorporated further in teaching and learning.

Table 1 details the primary objectives of top-cited studies. The vast majority of publications described integration of AI in medical education or the correlation of ML and AI in teaching and assessment of clinical skills. A significant number of articles related to the current practice of integration were either review or commentary articles, including an AMEE guide.[15] An integrative review of 37 studies was also identified,[17] which described 3 primary uses of AI in medical education including learning support (n=32), assessment of students' learning (n=4), and curriculum review (n=1). Also, main challenges of AI implementation in medical education were identified as difficulty in assessing the effectiveness of AI and technical challenges developing AI applications.

Table 1: Primary objective and types of publication

	Type publication				Total
Main Objectives	**Commentary**	**Correlation Analysis**	**Survey**	**Review**	
The need for integration of AI in medical education	11	1	-	7	19
Correlation of AI/ML in skills training, assessment, and giving feedback.	3	10	-	5	18
Attitude, perception, knowledge of students and residents towards AI	-	-	7	-	7
Application of AI/ML in teaching, learning and clinical reasoning	2	2	1	1	6
Total	**16**	**13**	**8**	**13**	**50**

At least 7 articles assessed perceptions and awareness of medical students and residents about the use of AI in medical practice, and whether, they were 'concerned' that their job would be taken over. Most (6/7) of the articles were published in 2018-2020. The overall impression was that the medical students were aware of the potential applications and implications of AI, although there was some degree of anxiety amongst the radiology residents, they did not worry that AI would replace the need for the physicians. Almost all agreed that AI should be included in medical training.[37]

The sections below present results based on all 218 relevant publications.

Core Journals

We applied 'Bradford's law', which classifies journals in a field of study to 'zones' based on total number of articles published in that field. Bradford's law states that "If journals were arranged in order of decreasing productivity of articles on a given subject, they may be divided into a nucleus, particularly devoted to the subject, and several zones containing the same number of articles as the nucleus".[38]

In the current study, the journals were divided into three zones with an almost equal number of publications, (Figure 3A). A total of 11 core journals published 72 articles; another 60 and 71 articles appeared in 2nd and the 3rd zones, respectively. Figure 3 also shows the distribution of citations received by each zone. Zone 1 journals received 26% of all citations. This shows that Zone 1 journals are much more frequently cited than the journals included in zone 2 and zone 3.

We then looked at the source dynamics. Figure 3B shows, that although a significant number of articles describing the technical details continue to be published, more recently, there is a surge in publications in journals like Academic Radiology, Academic Medicine, Medical Teacher, and Journal of American College of Radiology.

Authors Productivity

To describe the productivity of authors and the development of a particular field, Lotka[39] described the frequency of appearance of authors. According to the Lotka's law, the relative frequency distribution of author productivity is predicted to be hyperbolic inverse square function. It means that a small number of authors in a field publish the majority of articles.[40] Also, authors publishing 'n' number of articles is approximately $1/n^2$ of those publishing one: and the proportion of all authors who

publish once only is about 60% (39). We observed that more than 90% of authors had one publication so far (data not shown). It may be argued that AI in medical education is an emerging field, and Lotka's law may not depict actual picture at this stage.

Conceptual Structure:

Main Themes and Trends

Conceptual structure can be extracted using authors-supplied keywords. Here, we present the authors' keyword cloud, dynamics, and co-word analysis with the aim to explore the overall conceptual structure of published articles in AI and medical education.

Most frequently used keywords

Figures 4A shows the trends of annual occurrence of the most frequently used author supplied keywords as word-cloud. The figure shows that the most frequent keyword is the term "artificial intelligence" with 20 occurrences, followed by the terms "education" (18 occurrences), "medical education" (16 occurrences), "machine learning" (15 occurrences), and so on.

Keywords Growth/Trend

Following the trends of keywords allows observation about the evolution of terminology. This provides us with an overview of changes in the conceptual structure of research over time as shown in figure 4B. It is interesting to note that whereas, keywords 'machine learning', 'education', 'medical education' and 'medical students' continue to be used increasingly frequently, the term 'artificial intelligence' increased in medical education literature only recently and was the most frequently used keyword by the year 2020.

Co-word analysis

We next looked at keyword clusters. Thematic clusters are arrays of terms or combinations of words used in publications on a given topic. This analysis is also called a "co-words network" Callon, Rip.[41] Co-word analysis helps in understanding the main themes. The co-word occurrences reveal the three main clusters; "artificial intelligence", "machine learning" and "medical education" (Figure 4C). "Artificial intelligence" is used more commonly in connection with "radiology", "intelligent tutoring systems", and "medical decision making". The other main cluster combines "machine learning" with "objective skill assessment", "surgical skill assessment ", "radiology education", "behavioral and performance pattern", and "motion analysis". The third main theme of "medical education" co-occurs with "artificial intelligence", "machine learning" "medical informatics", "case-based reasoning", "intelligent tutoring systems", "patient simulation", "surgical training", and "robotic surgery". The overlap across the three clusters is natural, as these are closely interrelated. For example, patient simulation and e-learning were used commonly together with medical education and artificial intelligence.

Figure 3: Distributions of Journals according to Bradford Law and Source Growth

Figure 3A: Bradford's Law: Distribution of Journals in different Zones

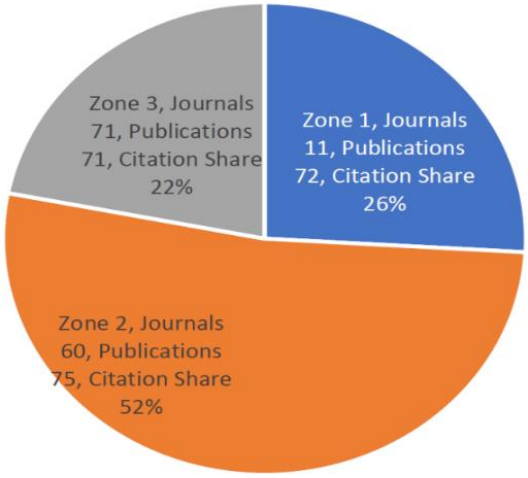
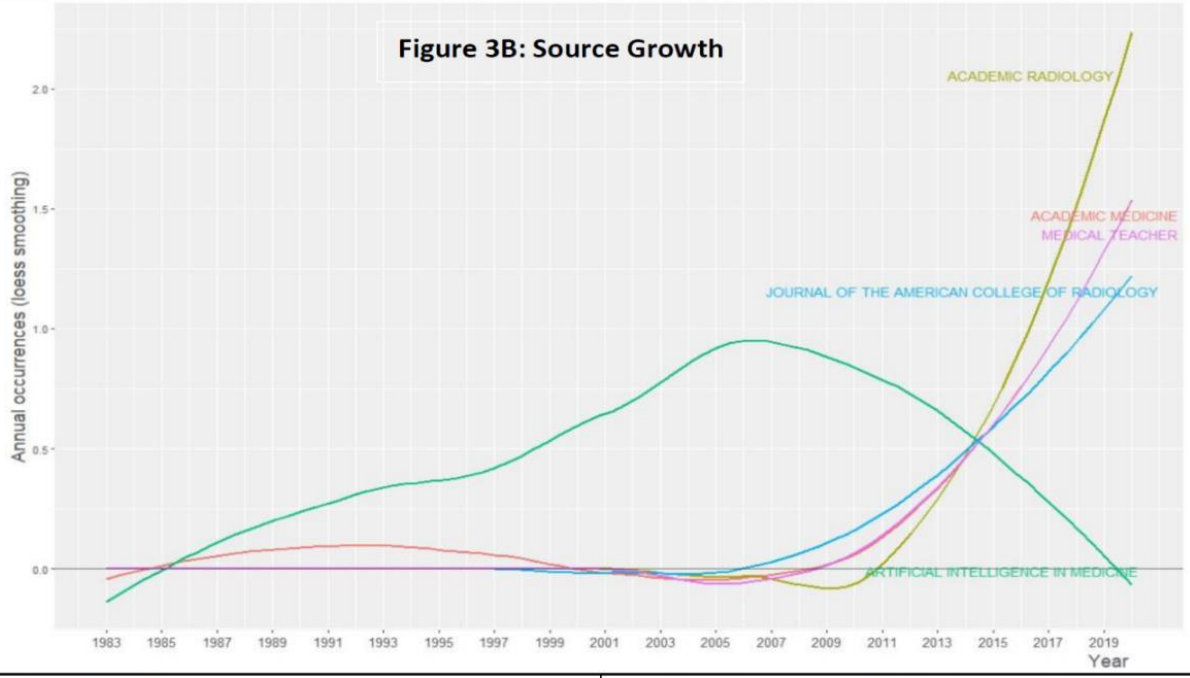


Figure 3B: Source Growth



List of Core Journals

1. Artificial Intelligence in Medicine
2. Academic Medicine
3. Academic Radiology
4. Journal of the American College of Radiology
5. Medical Teacher
6. Computer Methods and Programs in Biomedicine
7. Journal of Medical Internet Research
8. Journal of Surgical Education
9. Medical Education
10. International Journal of Computer Assisted Radiology and Surgery

Figure 3 A and 3B: Distribution of Journals according to Bradford Law and Source Growth

Figure 4: 4A author's keyword cloud, 4B author's keyword dynamic, 4C supplied based Keywords

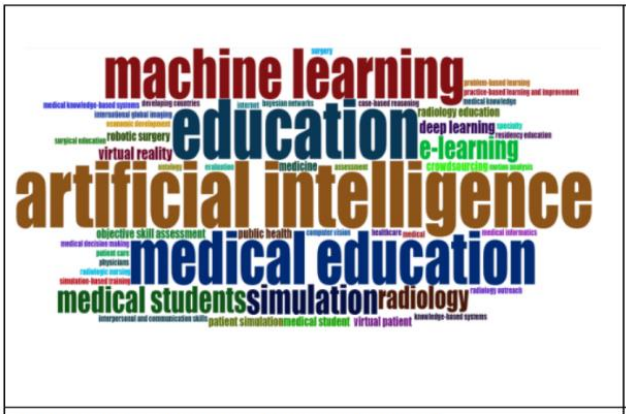


Figure 4A: Authors' keywords cloud

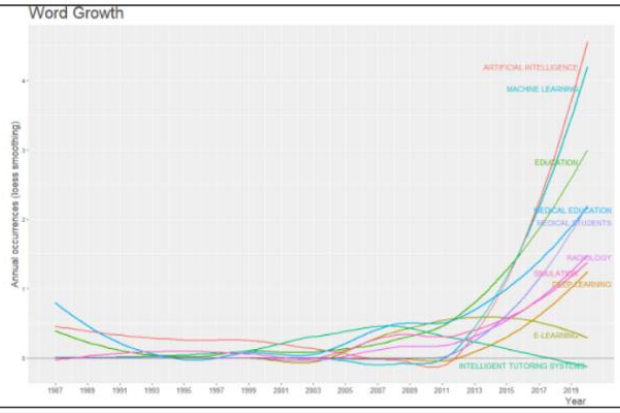


Figure 4B: Authors' Keyword Dynamics

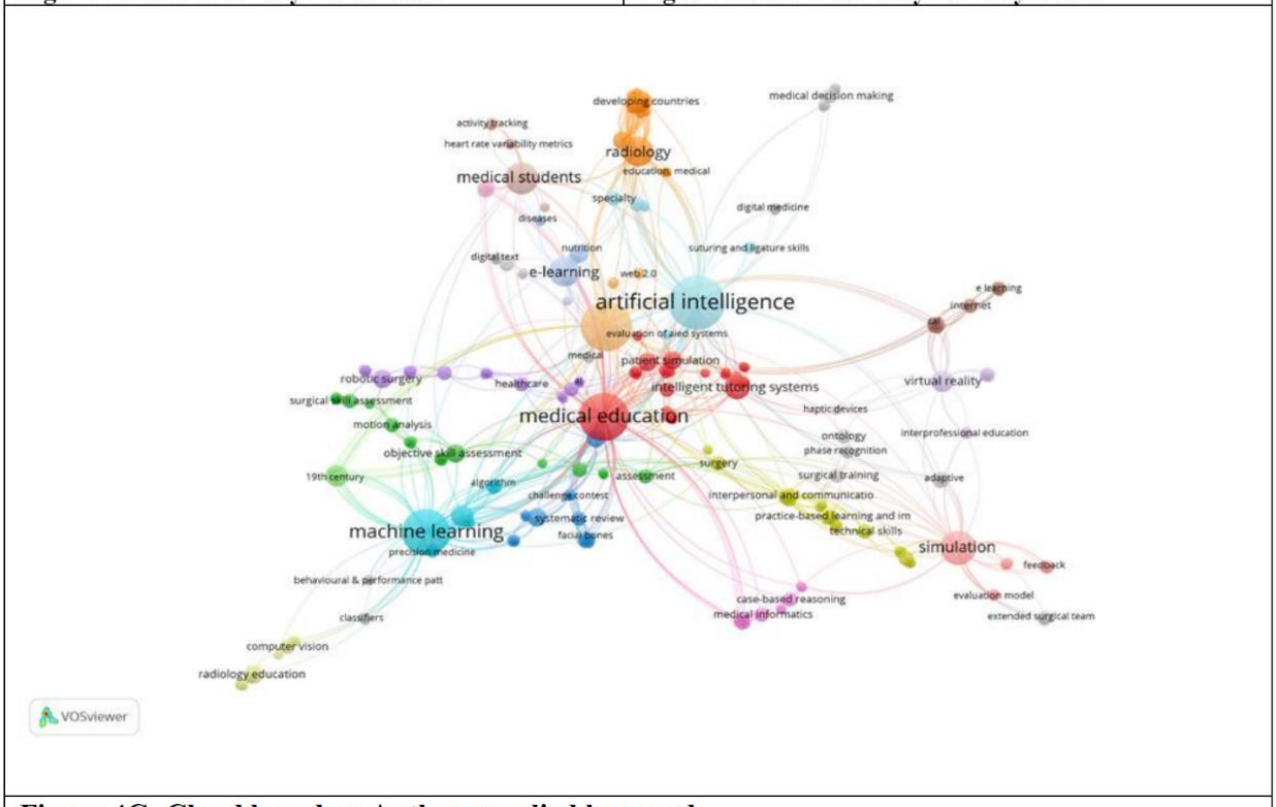


Figure 4C: Cloud based on Author supplied keywords

Discussion

The aims of this study were to review the existing information on the use of AI in medical education, the areas of teaching/learning and training where AI is being used currently, and the areas where AI is beginning to emerge. Moreover, the study was designed to study conceptual and social structure of AI in medical education using network analysis. We restricted our search to structured teaching and training programs. A sharp increase in the number of published articles was observed 2018 onwards. A significant number of articles reported the correlation of AI engines and machine learning with human performance. The publication trend was consistent with Bradford's law, but did not support Lotka's law. Keyword analysis revealed "artificial intelligence" as the most rapidly emerging

keyword over the last 3 years. Co-word analysis revealed "artificial intelligence", "machine learning" and "medical education" to be the main clusters.

We used a mixed design of citation-based review and content analysis, as it provides a more comprehensive picture. Citation-based systematic literature review was employed to study the pattern of publications, citation trends, identification of core authors, journals, keywords, co-words, and the temporal pattern of key words. Content analysis provides a quantitative approach to produce information from open-ended data of each paper that is explored, categorized, and evaluated.[42]

Reasons for the sudden and sharp surge in the number of published articles since 2018 remain speculative, but could be attributed to the fact that there were several reports calling for major reforms in medical education between 2000 and 2015.[43,10] In 2016, AI came to limelight when the World Economic Forum adopted a resolution to embrace Fourth Industrial Revolution (4IR) as a common and urgent priority (World Economic Forum Annual Meeting 2016, Mastering the Fourth Industrial Revolution). 4IR is defined as the "wave of technological advances that are changing the way we live, work, stay alive and interact with each other and machines" to meet the global challenges. The fundamentals of 4IR are AI, cloud computing, internet of things (IoT), and big data analysis.[6] AI has been hailed to have the potential to augment human intelligence, and has been hailed to have an impact on the processes and outcomes of healthcare as machines had on physical capabilities.[8]

Several recent articles have described attempts to develop, validate and correlate AI/ML tools to assess and provide feedback across a range of skills, including surgical skills, clinical reasoning skills and assessments of written material. For example, automated surgical skills assessment using accelerometer data was correlated with video analysis and shown to be superior in assessing surgical skills of suturing and knot-tying.[44] At the same time, automated systems were shown to save experts time and improve training efficiency. Another example is the assessment of clinical reasoning skills. Automated essay scoring (AES) system was used to assess constructed-response tasks ranging from short-answer tests to essay questions.[45] AES was shown to complement the use of selected response testing and provide medical students detailed feedback as part of formative assessment process. Yet, another example of studying correlation of ML with practice was the application Machine Learning to Assess Surgical Expertise (MLASE) checklist, to review manuscripts related to surgical expertise.[28] Differences were reported between medical (stronger in discussion quality) and computer science journals (better in study design).

The terms AI and ML are often used synonymously and interchangeably in literature, possibly because of an overlap.[46] AI has a wide range of scope, and can perform various complex tasks. ML on the other hand, has a limited scope, and can perform only those specific tasks for which the machines are trained. Strictly speaking ML produces predictions based on what it learnt from the past data, and AI enables a machine to simulate human behavior.[47] Since ML has paved the way for accurate predictions, and it is now possible to use those predictions in medical science, the phrase AI uses probabilistic methods and ML to categorize knowledge and logic together with embodied intelligence to perform human tasks.[48] Despite the distinctions, the two terms are used interchangeably in fields even where ML has become mainstay, such as, google search algorithms and Facebook auto-friend tagging suggestions. It is interesting that since the introduction of the term AI, more than 60 years back, it caught the attention of medical practice only in the last few years. The use of AI in medical field, especially medical education is in its infancy, and it is not surprising to see that the two terms are used interchangeably, and more recently AI has surpassed ML as the dominant keyword.

In summary, the practice of medicine is rapidly evolving from information age to the age of artificial intelligence. Machines have become an integral part of medical practice. The doctors of tomorrow need to be experts not only in the biomedical and clinical sciences, but also be able to deal with the interface between medicine and machines. Medical education needs to keep pace with changes in medical practice. To better integrate AI into the medical profession, measures should be taken to introduce AI into the medical school curricula, so that both medical professionals as well as the medical students understand the concept and applications of AI to maximize its use. The medical students not only need to be educated about AI tools, but also should develop skills to effectively use

advances in technology. We hope that the curriculum developers, deans and principals of medical schools, and the residency program directors will get a clear overview of the current status of research, teaching and the application of AI in medical education through this overview.

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