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REVIEW

Musculoskeletal education in undergraduate medical curricula–A systematic review

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Abstract

Rheumatic and musculoskeletal diseases encompass a vast spectrum of up to 200 conditions that are increasingly prevalent, with significant associated disability and socioeconomic burden. Their impact is pervasive, with musculoskeletal conditions being the second leading cause of years lived with disability worldwide, in addition to the 9th most common cause of disability-adjusted life years. It is therefore imperative that all graduating medical physicians are competent in their management, and that the quality of undergraduate musculoskeletal education is commensurate with patient and societal needs. A systematic literature review was conducted between April 1, 2021 and June 1, 2021 assessing the quality of undergraduate musculoskeletal education in medical schools. Educational interventions in musculoskeletal medicine were also included. Quality assessment appraisal of the studies was done using a Mixed Methods Appraisal Tool. One thousand and thirty-three titles were screened, and 44 studies were included in the final analysis. Our analysis of these studies showed that the quality of undergraduate musculoskeletal education, as determined by the cognitive mastery and clinical confidence of undergraduate medical students remains inadequate. Multiple educational interventions were assessed with mixed results. Despite the prevalence, and burden associated with rheumatic and musculoskeletal diseases, the musculoskeletal education of undergraduate medical students remains inadequate. Urgent international collaboration is required to devise teaching strategies and curriculum initiatives that are globally and reproducibly applicable and effective. Further research into educational interventions and teaching strategies is also required.

KEYWORDS
medical student, musculoskeletal education, orthopedics, rheumatology, sports medicine, undergraduate medical education

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1 | INTRODUCTION

"Musculoskeletal science" refers to the study of rheumatic and musculoskeletal health and disease. Musculoskeletal health is imperative for optimal human function by facilitating key elements of human life including mobility and dexterity,[1] and thus enables a physically active and productive life. Rheumatic and musculoskeletal diseases encompass a vast spectrum of up to 200 degenerative, inflammatory and auto-immune conditions which can affect any organ, albeit with a marked propensity for the musculoskeletal system.[2] They are extremely prevalent, with an estimated 2 billion people worldwide[3] living with a musculoskeletal condition.[4] Their impact is pervasive, and they are now the second leading cause of years lived with disability (YLDs) worldwide.[5] These conditions, owing to their disability and associated chronicity, are commonly associated with lack of physical activity, functional decline, loss of independence and social exclusion with subsequent decreased quality of life and mental well-being, in addition to increased risk of other comorbidities such as cardiovascular disease.[6–8] Furthermore, their socioeconomic burden is enormous. In Europe, they are considered to be the most expensive disease for healthcare services, with an estimated cost of more than 240 billion euros per year.[9] However, these direct costs fail to represent the high indirect costs that these conditions incur, including sick leave, with musculoskeletal conditions accounting for half of all European absences from work,[9] early retirement and a marked decline in national productivity.[10]

Consequently, it is no surprise that rheumatic and musculoskeletal conditions are frequently encountered in hospital and community care settings. They have been reported as the second most common reason for consulting a doctor, and in most countries account for 10%-20% of primary care visits.[11] Moreover, rheumatic and musculoskeletal disorders represent the most common class of complaint presenting to emergency departments.[12,13] Therefore, one can conclude that regardless of area of subspecialization, the majority of practicing medical physicians will likely encounter patients with musculoskeletal conditions frequently throughout their career.[14] It is thus imperative that all medical doctors have a robust foundation knowledge in musculoskeletal health and disease. Dedicated training in musculoskeletal science at the postgraduate level is predominantly subspeciality specific; therefore, the musculoskeletal knowledge and competency of many of our medical doctors in the management of these disorders is solely dependent on their exposure to musculoskeletal education at undergraduate level.

At the turn of the millennium, undergraduate education in musculoskeletal science was considered inadequate on a global scale, with the average time dedicated to its curriculum not commensurate with the global burden of disease.[15–17] This, coupled with the societal burden of these conditions, served as a catalyst for the launch of the "Bone and Joint Decade" (BJD) (2000-2010) by the World Health Organization in January 2000.[18] One of the most monumental outcomes of this was the formulation of global core recommendations for the learning outcomes of an undergraduate rheumatic and musculoskeletal disease education curriculum,[19] with this initiative since being validated in Canada,[20] and also emulated in Australia with their "National Core Competencies in Musculoskeletal Basic and Clinical Science" initiative.[21] However, since the exemplary efforts of these campaigns and curricula reform initiatives, no systematic literature review has examined whether the quality of undergraduate medical education in musculoskeletal science has correspondingly improved.

Therefore, in order to address this knowledge gap, the primary objective of our study is to systematically evaluate the quality of musculoskeletal science education for undergraduate medical students, with the secondary aim of systematically assessing various educational interventions in musculoskeletal science for undergraduate medical students.

2 | METHODOLOGY

2.1 | Data sources and searches

A systematic search of the literature was conducted using PubMed, Ovid Embase, Scopus and the Cochrane Central Register of controlled trials (CENTRAL), between April 1, and June 1, 2021. On July 28, 2021, the same search strategy was repeated to ensure any relevant studies published since June 1, 2021 were captured. The search was restricted to studies published since 2012, accounting for the most recent synthesis of the literature incorporating relevant studies prior to this.[22] The complete search strategy employed for each database is available in Appendix S1. Furthermore, included studies' reference lists were evaluated to identify additional relevant literature.

2.2 | Study selection

Citations retrieved from all databases were imported into Covidence, a web-based review management software. Duplicates were removed, and title and abstract screening was performed by 2 independent review authors (PH, EB) in order to identify studies suitable for inclusion (Table S1). The full text of positively identified studies were then assessed by 2 independent review authors (PH, EB) to ensure eligibility criteria were satisfied (Table S1). Any disagreements between the 2 review authors were resolved through discussion.

2.3 | Data extraction and outcome measures

Data extraction was undertaken using an electronic data collection form created specifically for this review. Baseline study characteristics were extracted by 2 independent review authors (PH, EB), including author, year, location, design, sample, intervention, outcomes and results.

2.4 | Data synthesis

In order to capture all empirical studies pertaining to the assessment of the quality of musculoskeletal education for undergraduate medical students, quantitative, qualitative and mixed method studies were suitable for inclusion in this review. These were assessed using an integrative review method, allowing for iterative comparisons across primary data sources.[23] A constant comparison method was implemented, converting extracted data into systematic categories, allowing the distinction of patterns, themes and relationships. Each intervention was further subdivided by outcomes according to the Kirkpatrick Model of curriculum evaluation[24] to give greater context to the results. Kirkpatrick's Model is a validated tool widely used for the evaluation of the quality of educational interventions and is comprised of 4 "levels", namely: reaction, learning, behavior and results.[25] The 1st "reaction" level refers to the level of satisfaction or confidence that participants have following a training program or curriculum initiative.[25] Level 2, the learning level, evaluates the level of knowledge, skills and values acquired by the participants from the program.[25] The 3rd level assesses the change in behavior of the participants as a result of the program, and the 4th level assesses the impact at an institutional level of the program or curriculum initiative.[25]

2.5 | Quality assessment

The methodological quality of each study was assessed by 2 independent review authors (PH, EB) using the Mixed Methods Appraisal Tool (MMAT), version 2018.[26] The MMAT permits evaluation of qualitative, quantitative and mixed method studies, with quality scores ranging from meeting 0 of 5 criteria (0) to meeting all of 5 criteria (5). This was performed to ensure that the interpretation of musculoskeletal education quality in each of the included studies, was supported by adequate appraisal of each study's methodology.

3 | RESULTS

3.1 | Characteristics of included studies

A total of 1126 studies were identified through database searches, and a further 2 studies were identified through reference and hand searches. Of these, 129 full-text articles were assessed for eligibility, and 44 were included in the final analysis (Figure 1). All studies were published between the years 2012 and 2021. Each studies' design, outcomes and relevant findings are displayed in Table 1 and Table S2.

The methodological quality of studies ranged from very low to very high. The studies assessing teaching methodology/curriculum initiatives had the lowest MMAT. The most commonly encountered limitations included absence of validated assessment tools/survey instruments, small sample size with inadequate representation of study population, absence of control, poor response rates and high attrition rates. However, no study received a score of 0, and no study was excluded from analysis secondary to poor methodological quality.

3.2 | Quality of musculoskeletal education

Eleven studies met the eligibility criteria for the evaluation of the quality of musculoskeletal education in medical schools (Table S2). These studies were carried out in the USA (n = 6), United Kingdom (n = 2), Africa (n = 1), Brazil (n = 1) and India (n = 1). Participant numbers in the studies ranged from 107 to 568, and the level of medical education varied within and between studies.

Concerning musculoskeletal education quality, the 2 key domains assessed in the included studies were knowledge and attitudes or perceptions of musculoskeletal disease, corresponding to levels 1 and 2 of Kirkpatrick levels of curriculum evaluation. Eight of the included studies assessed medical students' knowledge in musculoskeletal science, health and disease.[27–34] Two of the 8 studies[28,29] used the standardized National Board of Medical Examiners (NBME) musculoskeletal subject examination to assess students' knowledge of musculoskeletal conditions, and the other 6 studies[27,30–34] used the validated Freedman and Bernstein basic musculoskeletal competency examination.[35] For studies that used the Freedman and Bernstein cognitive examination, passing scores of both 70%[30,33,34] and 73.1%[27,31,32] were used. In 2 studies[27,34] 0 students met the passing criterion set out, while in the other studies the percentages of those meeting the passing criterion was as follows: 19.3%,[30] 21%,[6] 44.9%[33] and 47.8%.[31] Studies comparing test scores of students in different years of a medical program did demonstrate improvements in scores with increasing year, albeit to varying degrees.[30,31] The mean scores reported using the NBME musculoskeletal subject examination were 59.2% ± 10.6% for 2nd year medical students and 69.7% ± 9.6% for 4th year students in 1 study[28] and 73.8% ± 9.7% for final year students in a 2nd study.[29]

Nine studies reported on medical students' attitudes or perceptions of musculoskeletal education in medical training.[28,30,32–34,36–38]

Five of the 9 studies assessed clinical confidence on musculoskeletal topics using quantitative surveys.[28,30,33,34,36] Three studies[28,33,36] used a 5-point Likert scale for perceived confidence assessment, with a mean score of 2.5 across all medical years reported in 1 study,[36] a mean score of 2.8 ± 0.8 in 2nd year medical students vs 2.86 ± 0.86 in 4th year students reported in another,[28] and a statement of scores being higher in 3rd year vs 2nd year students reported in a 3rd study.[33] Two further studies used a 10-point scale to assess perceived clinical confidence where scores of 0-3 were considered low, 4-7 moderate and 8-10 high. Using this method, the mean score in 1 study was 3.7 ± 2.2,[34] and in another went from 3.18 in 1st year medical students to 4.77 in 4th year medical students.[30] Three studies assessed the perceived "adequacy" of musculoskeletal education, with 54% in 1 study,[37] and 68% in another study[32] regarding their education as being adequate, with 37% in another study describing their training as "poor".[38] In the single study that evaluated perceived competency,[32] 40% of students

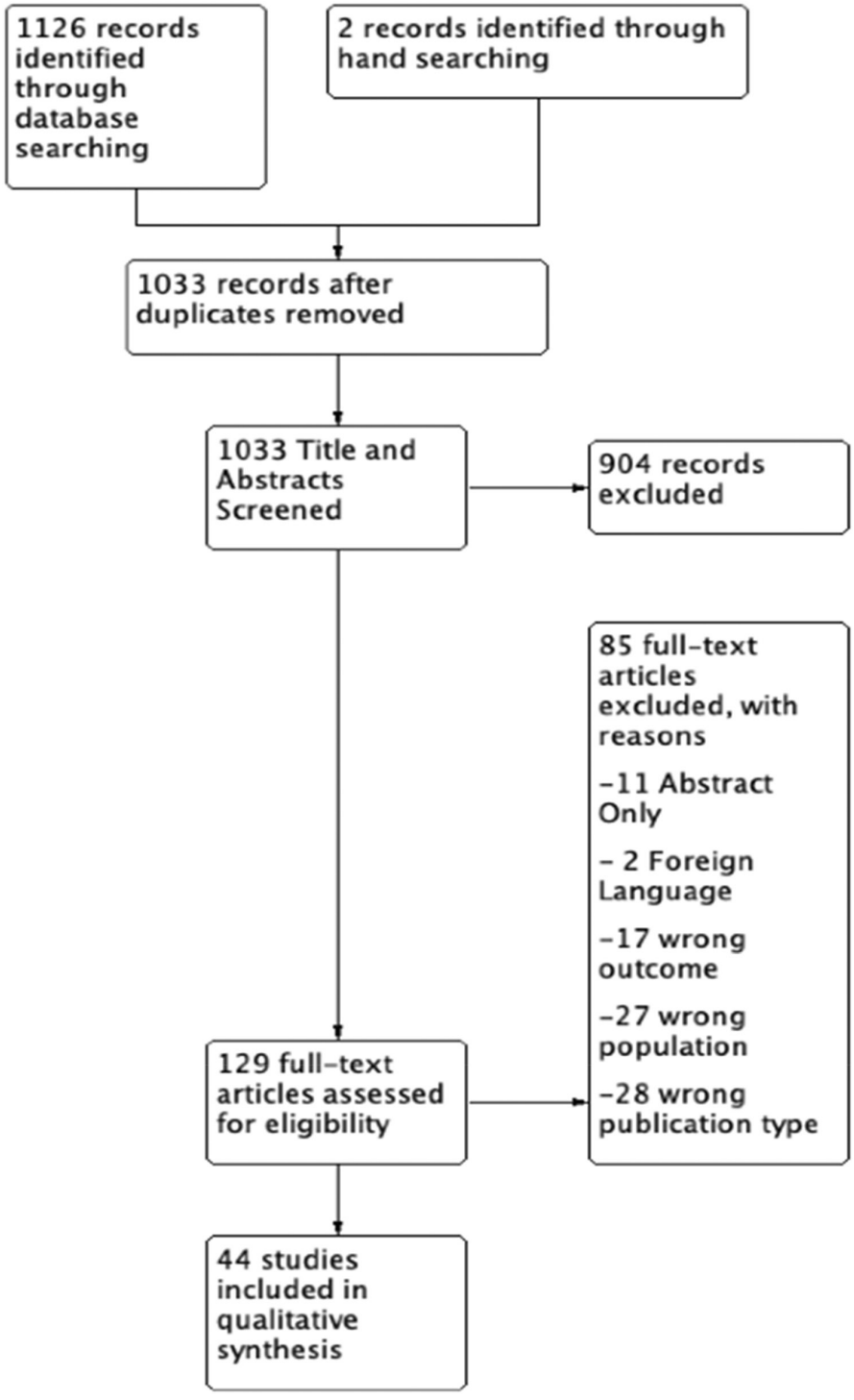


FIGURE 1 Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) flow diagram illustrating study selection.

reported feeling competent in musculoskeletal medicine. Of note, no study objectively assessed medical students' competency in musculoskeletal examination skills.

3.3 | Structured educational interventions in musculoskeletal education

Table 1 provides an overview of the 33 included studies evaluating various educational interventions in musculoskeletal medicine for undergraduate medical students. Given the diversity of interventions assessed, as part of the integrative review the interventions were sub-grouped, as detailed below, to facilitate comparison of relative effectiveness.

3.3.1 | Technology-assisted learning

In total 5 studies evaluated educational interventions involving technology-assisted learning and musculoskeletal medicine.[39–43]

TABLE 1 Overview of educational interventions in musculoskeletal education.

Reference	Method sample	Intervention (s) comparator (s)	Outcome (s) assessed	Kirkpatrick level (s) assessed	Result	Quality rating (MMAT)
1.Technology assisted learning (TAL)						
Back et al 2014[39]	Quantitative 5th y medical students (n = 53) Germany	Blended learning (BL) approach in PBL environment Compared to non-course group	Knowledge Skills Attitudes/ satisfaction	1,2	OSCE – no difference between groups MCQ – no difference in pre-test, slightly better results for BL vs control in post-test 74.3% found BL helpful in preparing for clinical situations 91% supported its continued use BL positively accepted by 97%	3
Back et al 2017.[40]	RCT Medical students (n = 130) Germany	Podcast vs textbook	Knowledge Attitudes/ satisfaction	1,2	Significant overall increase in knowledge in both groups ($P < .001$) -Textbook: post-test 60.9% (*SD* 12.6%) vs pre-test 48.1% (*SD* 12.6%) Podcast: post-test 66.2% (*SD* 12.6%) vs pre-test 44.5% (*SD* 12.4%). Podcast scored significantly better in post-tests ($P < .021$) Significantly higher approval of podcasts regarding comprehensibility, teaching efficacy or fun learning ($P < .05$)	4
Back et al 2019.[41]	Quantitative Medical students (n = 84) Germany	Audio-visual podcast vs digital book	Knowledge Satisfaction	1,2	Podcast learners showed a significantly higher gain of knowledge compared to text learners ($P < .011$). Positive ratings for both tools -podcasts were on average rated higher than were texts.	3
Schobel et al 2020.[42]	Quantitative Medical students (n = 306) Germany	Online podcasts in addition to main lecture series	Knowledge Perception	1,2	91%-95% considered the availability of lecture podcasts to be rather meaningful or very meaningful supplement to the lecture Use of online podcasts had no negative impact on examination performance	3
Wilson et al 2020.[43]	Modified randomized cross-over trial Medical students (n = 33) United Kingdom	High-fidelity virtual reality (VR) vs physical model simulation	Knowledge	2	In VR group, post-training score improved by 192.1% ($P < .00001$). In physical models group post-training scores improved by 163.1% ($P < .00001$) Overall no statistically significant difference in the total means of post-training test scores between the VR and physical models study groups ($P = .4354$)	3

TABLE 1 (Continued)

Reference	Method sample	Intervention (s) comparator (s)	Outcome (s) assessed	Kirkpatrick level (s) assessed	Result	Quality rating (MMAT)
2. Near peer/peer learning						
Schiff et al 2014.[44]	Quantitative study 4th y medical students (n = 71) USA	Near peer learning vs standard curriculum alone	Knowledge Attitude	1,2	Freedman + Bernstein median score− 83.6%. 60 (84.5%) students passed (ie >73.1%) 96% found near peer course appropriate for their level vs 26% for their medical school orthopedic curriculum 95% found near peer learning lectures excellent.	2
Kumar et al 2020.[45]	Quantitative Medical students (n = 61) United Kingdom	Near peer teaching (NPT)	Knowledge Attitude/ confidence	1,2	96.7% supported NPT for OSCE preparation. 98.4% felt NPT enhanced their knowledge Mean improvement in MCQ scores −1.3 ± 1.2 ($P < .001$) and clinical confidence 1.7 ± 1.2 ($P < .001$)	3
Anantharaman et al 2019.[46]	Quantitative 1st y medical students (n = 60) India	Peer-assisted learning (PAL) vs didactic methods	Knowledge Perception	1,2	PAL group higher mean scores for both the Upper and Lower limb sessions. Higher post-session scores vs pre-session scores in both PAL and didactic Majority of aspects of PAL were appreciated by students	4
Yamauchi et al 2021.[47]	Quantitative 5th y female medical students (n = 90) Japan	Peer role playing simulation program	Skills	1	Mini-CEX scores for physical examination, clinical reasoning and diagnosis and overall clinical competency were significantly higher in the simulation group than in the control group	3
3. Anatomy teaching strategies						
Ultrasound (US) based						
Knobe et al 2012.[48]	Randomized cross-over controlled trial 2nd y medical students (n = 234) Germany	• MSK US (+dissection) • Arthroscopy (+dissection) • Control (dissection only)	Knowledge Perception Skills	1,2	Arthroscopy superior in MCQ scores and student rating of spatial awareness, no significant difference in OSCE scores	3
Walrod et al 2018.[50]	Quantitative 1st y medical students (n = 27) USA	2 intervention groups: Both groups received a lecture on relevant joint anatomy (shoulder or knee), then each group received hands-on US scanning of their respective joint	Confidence Skills	1,2	All students performed significantly better on the knee examination, irrespective of instructional group. Shoulder group performed significantly better than the knee group	2

(Continues)

TABLE 1 (Continued)

Reference	Method sample	Intervention (s) comparator (s)	Outcome (s) assessed	Kirkpatrick level (s) assessed	Result	Quality rating (MMAT)
TAL						
Mitrousias et al 2018.[49]	Quantitative 1st y medical students (n = 72) Greece	2 intervention groups: 1st received 4 h of lectures followed by 4 h of cadaveric-based lab work. 2nd group received the same 4 h of lectures but then received 4 h of anatomy simulation using 3D anatomy software	Knowledge Perceptions	1,2	The group using the 3D software showed better performance in examinations, compared to students using prosection (mean: 55.88 ± 19.60 vs 48 ± 16.11; $P = .05$, Cohen's $d = .5$). No statistically significant difference regarding student satisfaction between either intervention	3
Ruthberg et al 2020.[51]	Quantitative 2nd y medical students (n = 48) USA	2 intervention groups: 1st group received standard cadaver-based anatomy instruction. Second group used the HaloAntomy VR system	Knowledge	1	No significant difference was found in MCQ scores between the groups; however, the VR group spent an average of 4.6 h using the system while the cadaver learners required 7.3 h in the dissection lab	3
Sol et al 2021.[52]	Quantitative 1st y medical students (n = 187) Peru	Single intervention: use of a 3D anatomy App to aid conventional anatomy study	Knowledge	1	No association was found between the use of the 3D App and academic performance in the adjusted model (aβ = 0.17; 95% CI: −0.45-0.80).	3
Santos et al 2021.[53]	Quantitative Medical students (n = 611) Portugal	Computer-aided learning platform for anatomy	Knowledge	1	A positive correlation was detected between the number of computer-aided learning sessions the students partook in and their results in the end of year assessment of MSK anatomy ($r = .761$, $P < .001$)	3
Prosection-based						
Peeler et al 2018.[54]	Quantitative Medical students (n = 93) Canada	Prosection-based vs dissection-based laboratory instruction	Knowledge Perception	1,2	No difference in academic performance. Each group ranked both methods high	2
Au et al 2018.[55]	Quantitative 4th y medical students (n = 144) Australia	5 intervention groups: Instructional cards and online module Skeletal model Cadaveric ankle model Cadaveric ankle and patellar model Cadaveric ankle, patellar and hip model	Knowledge Perception	1,2	Compared to the instructional cards group the other 4 groups showed a 10.8%-19.2% improvement in total test score ($P < .01$) and an 18.4%25.3% improvement in self-reported understanding and confidence in performing joint relocations ($P < .01$). Notably there was no significant difference between the skeletal model and the cadaveric model groups	3

TABLE 1 (Continued)

Reference	Method sample	Intervention (s) comparator (s)	Outcome (s) assessed	Kirkpatrick level (s) assessed	Result	Quality rating (MMAT)
Mitrousias et al 2020.[56]	Quantitative 1st y medical students (n = 60) Greece	Group 1 attended lectures and attended cadaveric prosections while group 2 attended lectures and used plastic models in the lab setting	Knowledge Perception	1,2	No significant difference in students' performance was observed between the group using prosections and the group using plastic models (32.2 ± 14.7 vs 35.0 ± 14.8, respectively; $P = .477$). Furthermore, no statistically significant difference was identified in relation to students' satisfaction using either learning modality ($P = .441$)	4
Near peer initiatives						
Shields et al 2015.[57]	Quantitative 1st y medical students USA	Near peer interprofessional interaction – 2nd y physical therapy students delivered an MSK anatomy demonstration to 1st semester medical students	Attitudes	1	Both student groups reported high satisfaction (>4 on 5 point scale) with the quality and value of IPE session. Both groups in favor of future near peer IPE interactions	1
Other						
Singh et al 2019.[58]	Quantitative 1st y medical students (n = 66) Barbados	All students were assigned a muscle in the upper or lower limb and were instructed to complete an interactive presentation on that muscle	Knowledge Perceptions	1,2	Students achieved better scores in post-presentation MCQs ($P < .01$) and the marks of in-course and final examinations also showed significant improvement ($P < .01$)	3
4. Other strategies						
Soukup et al 2012.[59]	Quantitative Medical students (n = 41) United Kingdom	1 d intense course on orthopedic skills and subspeciality awareness	Knowledge Confidence Perception	1,2	Mean pre-course self-reported knowledge and confidence score 1.7 ± 0.055 ($P < .0001$), mean post-course score 4.1 ± 0.046 ($P < .0001$) 87% thought surgical skills courses should be integral to undergrad curriculum. 92% did not believe their medical school provided enough time for surgical skills training	2
McDaniel et al 2020.[71]	Quantitative 1st, 2nd, 3rd, 4th y medical students (n = 179) USA	Shortened MSK curriculum 49 h vs longer 78 h	Knowledge Confidence	1,2	Longer curriculum associated with significantly improved knowledge as per Freedman and Bernstein (78.1% *SD* 18.5%) vs shorter MSK curriculum (45.3% *SD* 19.8%) ($P < .0001$) And also confidence (6.08/10 *SD* 1.81 vs 5.74/10 *SD* 1.67)	4

(Continues)

TABLE 1 (Continued)

Reference	Method sample	Intervention (s) comparator (s)	Outcome (s) assessed	Kirkpatrick level (s) assessed	Result	Quality rating (MMAT)
Vioreanu et al 2013.[60]	Quantitative 4th y medical students (n = 140) Ireland	2 wk interactive MSK teaching module vs traditional methods	Knowledge Perception	1,2	20% pass rate pre-module, increased to 85% post-module. 48% of students found the interactive tutorial approach to be the single most effective teaching method of the course	4
Boulila et al 2021.[64]	Mixed methods 2nd y medical students (n = 9) Canada	3 interprofessional workshops	Knowledge Confidence Perceptions	1,2	Knowledge scores (out of 10) all increased significantly from baseline to post-workshop. Shoulder 6.7 to 8.1 ($P < .02$); knee 5.4 to 8.5 ($P < .002$) and lower back 3.8 to 7 ($P < .15$). Knowledge scores also remained above baseline at 6 mo, but the difference was not significant. Confidence scores out of 30, increased from 18.4 at baseline to 27.2 post-workshop and remained above baseline at 24.2 at 6 mo f/up. Students highly valued the small group interprofessional format, the hands-on practice with feedback	3
Kelly et al 2014.[61]	Quantitative Medical students (n = 154) Ireland	1 wk intensive course with consultants and senior registrars	Knowledge Attitudes	1,2	72% rated MSK to be of major or critical importance in career. Mean pre-test Freedman and Bernstein score 48.2% ± 14.2%, with pass rate of 3.3% vs post-test mean score of 75.3% ± 15.02% with a pass rate of 61%. End of y 69.9% and 96.7% passed the EMQs and OSCE respectively	4
Guo et al 2016.[62]	Quantitative 2nd y medical students (n = 60) Canada	Extracurricular MSK clinical skills workshop	Clinical skills Confidence	1,2	Self-rated confidence levels for all 8 MSK PE – significantly higher ($P < .01$) after the workshops. 9 mo post-workshop – 39.1% reported increase in confidence carrying out MSK PE during clerkship. End of year OSCE – average score for workshop ppt 7.71 ± 0.6, vs class average 7.68 ± 0.73. 91.3% of ppt reported increased confidence in performance in OSCE secondary to workshop	3
Melo et al 2017.[63]	Quantitative 1st y medical students (n = 20) Australia	MSK vs non-MSK specialist training	Knowledge Clinical skills	1,2	No difference in skill level or knowledge in the area of MSK PE between those trained by MSK specialist vs non-MSK tutors. Both groups demonstrated improvement	4

TABLE 1 (Continued)

Reference	Method sample	Intervention (s) comparator (s)	Outcome (s) assessed	Kirkpatrick level (s) assessed	Result	Quality rating (MMAT)
Kelly et al 2018.[65]	Randomized controlled trial 3rd y medical students (n = 96) Ireland	Case-based teaching vs bedside teaching	Skills Perceptions	1,2	No difference in average final OSCE score between the bedside teaching group (64.2% *SD*:11.98) and case-based teaching group (65.3%, *SD* 9.02) -mean difference 0.34, 95% CI -3.79-4.47, *P* = .872. 95% of participants felt case-based teaching was an important component in their learning	4
Mitra et al 2015.[72]	Quasi-randomized trial 3rd y medical students (n = 170) Malaysia	Web-based formative assessment with automated feedback vs paper-based formative MCQ test with face-to-face group feedback	Knowledge	2	No significant difference between the mean summative scores of the 2 groups	3
Perrig et al 2016.[73]	Quantitative 4th y medical students (n = 48) Switzerland	Short small group course with systematic feedback vs regular clerkship activities only	Clinical skills at beginning (T0), end (T1) and 4–12 mo (T2) after the clerkship	2	T0 – no significant differences. At T1 and T2 control group showed no significant changes in clinical skills compared to T0, whereas the intervention group significantly improved at T1 ($P < .001$). This was sustained for clinical skills and MSES at T2 ($P < .05$) but not for Interprofessional skills at T2	5
Khorsand et al 2018.[74]	Quantitative Medical students (n = 986) USA	Early MSK medicine exposure in preclinical y vs exposure just prior to completing preclinical y	Knowledge	2	Overall USMLE scores and scores on USMLE subset on MSK, skin and CTD showed no difference between the groups. -Statistically significant lower performance on Freedman and Bernstein knowledge assessment for those in the new preclinical curriculum vs those on old model in both knowledge ($P < .001$) and proficiency ($P < .01$)	3
Zabel et al 2019.[66]	Quantitative 3rd y medical students (n = 92) Germany	3 distinct teaching methods for both knee and shoulder examination -G1. Mutual examination -G2. Teaching associate examination then mutual -G3. Examination by the instructor then mutual	Clinical skills	2	Directly after training G2 and G3 performed significantly better than G1 regarding overall scores ($P < .001$) and all 4 checklist parts ($P < .001$) with no significant differences between G2 and G3 5 wks later – G2 performed significantly better than G1 at shoulder examination ($P = .003$) and significantly better than G3 ($P = .025$) regarding knee examination	4

(Continues)

TABLE 1 (Continued)

Reference	Method sample	Intervention (s) comparator (s)	Outcome (s) assessed	Kirkpatrick level (s) assessed	Result	Quality rating (MMAT)
Rohlfsen et al 2020[75]	Quantitative 2nd y medical students (n = 286) USA	Comparison of 6 active learning modalities -Live patient encounters (LPE) -Augenblick -PBL -Gout Racer Video game -Simulation knee injection -Rheumatology Remedy e-module	Perception	1	LPE had significantly higher student-rated effectiveness scores. Its mean effectiveness score of 4.77 – followed by Augenblick (4.21), PBL (4.11), Gout Racer video game (3.49), Rheumatology Remedy e-module (3.49) and simulation knee injection (3.09)	4

Abbreviations: BL, Blended Learning; CBT, Case-Based Teaching; CTD, connective tissue disease; EMQs, extended matching questions; IPE, interprofessional education; MCQ, multiple choice questions; mini-CEX, mini-clinical evaluation exercise; MMAT, Mixed Method Appraisal Tool; MSES, musculoskeletal specific exam skills; MSK, musculoskeletal; OSCE, objective structured clinical examination; PBL, problem-based learning; PE, physical examination; RCT, randomized controlled trial; USMLE, United States Medical Licensing Examination.

This included 1 randomized controlled trial,[40] 1 modified randomized cross-over trial[43] and 3 quantitative studies.[39,41,42] Three studies evaluated podcast learning compared to either textbook or lecture series.[40–42] One study evaluated a blended learning (BL) approach[39] and one assessed high-fidelity virtual reality.[43] There was no difference in terms of knowledge or skill using a BL approach vs problem-based learning (PBL) alone; however, 74.3% rated BL helpful in preparing for clinical practice, and it was positively accepted by 97%.[39] Two of the 3 studies evaluating podcasts demonstrated a significantly higher gain of knowledge vs the use of textbooks;[40,41] however, the 3rd study evaluating podcasts found no higher gain of knowledge vs a standard lecture series.[42] In all 3 studies, podcasts scored positively in terms of student satisfaction and perception.[40–42] The study evaluating knowledge gained using virtual reality vs physical model simulation showed no overall statistically significant difference between the 2.[43]

3.3.2 | Near peer/peer-assisted learning

Two studies evaluated near peer learning (NPL)[44,45] and 2 further studies evaluated peer-assisted learning (PAL).[46,47] Studies evaluating NPL[44,45] assessed both knowledge and perception, with the first demonstrating a median Freedman and Bernstein score of 83.6% post-NPL, with 95% deeming NPL excellent.[44] The second study showed a statistically significant improvement in multiple choice question scores and clinical confidence post-NPL intervention, with 96.7% supporting its use in objective structured clinical examination (OSCE) preparation.[45]

The 1st study evaluating PAL resulted in greater knowledge gain on assessment in PAL group vs didactic learning group, with good appreciation by students of most aspects of PAL.[46] The second study assessing PAL evaluated clinical skills via an mini-clinical evaluation exercise examination, demonstrating significantly higher physical examination, clinical reasoning and overall competency using PAL vs control.[47]

3.3.3 | Musculoskeletal anatomy instruction

Eleven studies evaluated educational interventions in musculoskeletal anatomy education for medical students.[48–58] (Table 1) Two studies evaluated ultrasound (US) based techniques.[4850] One compared US to arthroscopy,[48] with arthroscopy demonstrating superiority in both knowledge and perception outcomes, and the other study reported the benefit of US in improving relevant surface anatomy identification.[50]

Four studies examined the application of technology-assisted learning (TAL) to musculoskeletal anatomy.[49,51–53] One study demonstrated how the use of 3D anatomy simulation yielded superior cognitive examination performance compared to prosection-based learning,[49] with a second study reporting the lack of a significant difference in terms of superior knowledge acquisition with the use of a virtual reality system.[51] However, this same study found that the knowledge

acquired was done so in a significantly shorter time frame than standard cadaver learning.[51] A further study demonstrated how the use of a computer-aided learning platform had a positive correlation with examination results,[53] in contrast to a final study where no association was found between the use of a 3D anatomy App and academic performance.[52] The use of prosection teaching methods was assessed in 3 studies,[54–56] with all 3 failing to demonstrate a significant difference in either knowledge or perception acquisition using prosection-based methods of musculoskeletal anatomy delivery vs comparator. One study evaluated near peer interprofessional learning in musculoskeletal anatomy demonstration, with high student satisfaction reported.[57] A final study demonstrated a significant knowledge gain following an interactive presentation program.[58]

3.3.4 | Other strategies

Outside of the subgroups outlined above, a number of additional learning and teaching methods were evaluated (Table 1). Four studies[59–62] assessed the role of intense short periods (of varied duration) of musculoskeletal education according to 2 levels of Kirkpatrick's curriculum evaluation. One study[59] demonstrated the significant knowledge and confidence gained from a 1 day intense course on orthopedic skills (mean pre-course score 1.7 ± 0.055 [$P < .0001$], mean post-course score 4.1 ± 0.046 [$P < .0001$]). A further 2 studies demonstrated the significant knowledge gain from a 2 weeks intensive interactive musculoskeletal module, with the pre-module pass rate of 20% on a standardized assessment, increasing to 85% post-module,[60] and a 1 week intensive course showing mean pre-test Freedman and Bernstein scores of $48.2\% \pm 14.2\%$, with a pass rate of 3.3% increasing to post-test mean score of $75.3\% \pm 15.02\%$ with a pass rate of 61%.[61] Furthermore, an extracurricular clinical skills workshop showed significantly higher self-rated confidence levels in musculoskeletal physical examination post-workshop ($P < .01$).[62]

The delivery of education from a musculoskeletal specialist, compared to a non-specialist did not result in any increase in skill level or knowledge.[63] One study examined the role of interprofessional workshops, reporting a significant increase in knowledge and confidence scores from baseline to post-workshop, benefits which were sustained at 6 months follow-up.[64]

Case-based teaching was compared to bedside teaching in a randomized controlled trial, and results concluded there was no difference in the average final OSCE score between each of the groups; however, case-based teaching was well received by the students.[65] The benefit of a teaching associate was demonstrated in 1 study with significantly better clinical skills performances when compared to peer and instructor led examination.[66]

4 | DISCUSSION

Despite significant curriculum reform efforts, our findings suggest that medical students, regardless of year of study or geographical location, fail to demonstrate adequate cognitive mastery in the topic of musculoskeletal science, as demonstrated by the high failure rates in the validated Freedman and Bernstein examination,[27,30–34] with less than half of participants passing in all included studies and a startingly 0% pass rate in 2 of the included studies.[27,34] Interestingly, using the NBME musculoskeletal subject examination, the mean scores achieved were higher.[28,29] With such a discrepancy in results between the 2 assessment tools, notwithstanding other sources of confounding and bias within the individual studies, one would question the effectiveness, reliability and indeed validity of these assessment tools in assessing musculoskeletal cognitive mastery and competence in this population. Furthermore, despite being the only assessment tools to populate the literature and undergo validation in musculoskeletal education, they both fail to assess musculoskeletal clinical skills, or psychometric factors, both core components of ultimate competency in the discipline. Moreover, the perceived confidence and attitude of medical students for musculoskeletal disease is concerningly low.[28,30,33,34,36] Despite variability in the tool assessing clinical confidence between studies, and marginal increments observed with advancing years of medical education,[28,30,33] no student reported above average confidence in musculoskeletal medicine in our analysis, regardless of stage of study.[28,30,33,34,36] Furthermore, student-reported adequacy of their musculoskeletal education was consistently suboptimal.[37,38]

Although not directly assessed, one can also anticipate that poor clinical confidence in musculoskeletal clinical skills translates to inadequate clinical skills. One can thus infer that such a graduate will lack competency to provide an optimal standard of care for patients with musculoskeletal conditions. Given the current, and indeed increasingly prevalent nature of these conditions, coupled with the disability they impose, our findings serve as a catalyst for the urgent establishment of an international collaboration, to develop strategies to ensure the enhancement of undergraduate musculoskeletal education. Further research is required to determine factors that enhance musculoskeletal knowledge, clinical skills and overall confidence.

In response to these identified deficiencies, we proceeded to systematically evaluate structured educational interventions in undergraduate medical musculoskeletal education, in order to determine superior methodologies, and novel pedagogical techniques to support the necessary curriculum reform.

In recent years, the transfer of knowledge via TAL has become an integral part of medical education, and has revolutionized instructional methods implemented to facilitate learning.[67] BL refers to the systematic integration of both online and face-to-face teaching methods.[68] Only 1 study evaluated the role of BL,[39] in combination with PBL in musculoskeletal education, and demonstrated good student satisfaction; however, there was no impact on knowledge or skills vs PBL alone. As only 1 study assessed this educational intervention, findings should be interpreted with caution; however, further studies are required to assess this modality, given its reported superiority in other medical disciplines. The findings in the review suggest podcasts are a positive adjunct to a musculoskeletal

education curriculum, with good student satisfaction and also knowledge gain.[40–42] However, given the limited number and heterogenous nature of studies assessing TAL in our review, coupled with rather ambivalent findings, definitive recommendations of its use in musculoskeletal education are precluded.

Dating back to 1990, Hartman concluded that the use of peer educators "provides many benefits to the student's teacher and his/her classmate".[69] PAL and NPL draw on Vygotsky's "zone of proximal development",[70] where in order to learn something new, 1 must be at the right distance between prior and new knowledge, something often more easily appreciated by peers as distinct from faculty experts. Our review of the 4 studies evaluating both PAL and NPL in musculoskeletal education demonstrate promising results in 2 levels of Kirkpatrick learning outcomes, or all 3 domains of knowledge, skills and attitude/perception.[44–47] Although studies are limited, these findings are promising given the amenability of NPL and PAL, particularly in the setting of poor resources or economic constraints.

Musculoskeletal anatomy serves as the foundation of basic musculoskeletal knowledge, thus it is imperative that this component of a musculoskeletal undergraduate curriculum is optimally delivered. The educational interventions assessed in this review were diverse, thus in order to enable comparison they were grouped into subsections (Table 1). Results using the various strategies were mixed. Very interestingly, 2 studies[55,56] showed no significant difference between the use of plastic models and cadaveric models in terms of student knowledge acquisition or their self-declared satisfaction with the learning modalities. Although further studies are required, this may allow for the reduction on the reliance on cadaver-based learning of anatomy which is economically costly. The demonstrated significant improvements in student performance through the use of interactive learning methods which included the use of song, poetry and dance[58] is an alternative and exciting low-cost method, that most certainly warrants further evaluation.

The benefit of an intense musculoskeletal curriculum in terms of knowledge and confidence acquisition was demonstrated in a number of studies.[59–62] This provides promise for a strategy to circumvent the obstacles posed by the introduction of a new curriculum in an already time-constrained undergraduate medical curriculum. Unfortunately only 1 study has been conducted assessing the benefit of interprofessional education.[64] Although this study was underpowered, it did show a significant benefit of an interdisciplinary approach to musculoskeletal education, a concept which is gaining momentum within medical education throughout a number of disciplines, largely due to its assimilation to the professional working environment. The benefit of teaching associates was also only evaluated in 1 study, again demonstrating significant benefit in terms of clinical skills acquisition.[66] The use of teaching associates utilizes multimodal feedback, with demonstrated benefit in motor learning and clinical skills acquisition.[66] This is of particular interest in musculoskeletal clinical skills education; however, further studies are required.

There are a number of limitations within this review that must be addressed. The integration of diverse methodological studies in a review can be complex, with the potential for the introduction of bias. The results of this review should therefore be interpreted with caution given the low methodological quality of a number of included studies. Additionally, only studies published in the English language were included, potentially resulting in significant bias. Furthermore, there are a number of inherent limitations secondary to the heterogeneity of populations, study design, interventions and outcomes that reduce the generalisability of results to all levels of medical trainees in varying educational settings, and also limit the ability to draw definite conclusions from findings.

5 | CONCLUSION

The findings of our review highlight the persistent inadequacies in the quality of musculoskeletal education for undergraduate medical students. We have also demonstrated how various educational interventional methods can enhance students' knowledge and confidence in the discipline. Further international collaborative research with higher power and improved methodological quality is required, particularly of the curriculum initiatives which have demonstrated benefit in this review. Our findings most certainly serve as an impetus for change, requiring the future of undergraduate musculoskeletal medical curricula to reflect societal needs.

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CONFLICTS OF INTEREST

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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