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Research

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Current State of Three-Dimensional Printing for Simulation Training of Interventional Radiology Trainees

3D Printing for Interventional Radiology Trainees

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Abstract

Objectives: The purpose of this review was to assess the use of three-dimensional (3D) printing in interventional radiology (IR) simulation experiences.

Materials and Methods: A literature query was conducted in April 2020 for articles discussing 3D printing for simulations in numerous library databases using various search terms.

Results: While trainee feedback is generally supportive of 3D printing within the field of IR, current applications utilizing 3D printed models are heterogeneous, reflecting a lack of best practices standards in the realm of medical education.

Conclusions: Presently available literature endorses the use of 3D printing within IR. 3D printing has the potential to expand within the field, as it offers a straightforward, sustainable, and reproducible means for hands-on training that ought to be standardized.

Keywords: three-dimensional printing, simulation training, high fidelity training, interventional radiology

Introduction

Simulation-based training is a method of experiential teaching that reproduces a real-world scenario in a controlled setting. Conventionally used to replicate high-risk tasks for military training, aviation, and aerospace professions [1], simulation-based training has become a prominent complement within medical education [2,3]. Simulations can be performed outside of working hours, and certain procedural skills can be customized or repeated for a trainee's needs, without compromising patient safety. Radiology residents and medical students are generally supportive of simulation use, as both groups have reported higher procedural confidence after completing a session on a number of diagnostic or interventional simulators [4-10].

This type of training is especially relevant for procedural specialties like IR, where learners rely on haptic cues for skill acquisition [11]. Angiography suite learning involves attempting procedures while patients are minimally sedated yet cognizant of their surroundings. This can increase patient anxiety and apprehension, compromise patient safety and satisfaction, and hinder the teaching experience [12, 13]. Current simulation options are varied, ranging from video games for inferior vena cava filter placement or percutaneous image-guided interventions [14, 15], phantom simulators for Computed Tomography (CT) biopsies [10, 16-18], or animal or cadaver models to practice endovascular access or interventions [13, 19]. Several studies have used simulators to demonstrate improved procedural technique, either in device manipulation [20-22], successful vessel cannulation [23], or reduced procedural time and radiation use [24-26]. There is burgeoning evidence demonstrating skill retention after the simulation [7], which has translated to improved patient outcomes. Such an example was documented by Andretta et al., who noted increased procedural proficiency and successful PICC line placement among interns who completed a simulation rotation on ultrasound-guided access [27].

Despite its advantages, simulations have several operational limitations and a correlative cost-benefit ratio. Simulations can be categorized by fidelity, or degree of situational realism, anatomic accuracy, or physiologic replication [28]. Although high-fidelity models have been shown to significantly increase technical performance in a simulated environment [29], they are often of higher cost, limited availability, or if using animal or cadaver sources, raise ethical concerns [12, 19, 28]. The holy grail in simulation medicine is the ability to develop a reproducible, realistic, and inexpensive product, which may be refined via three-dimensional (3D) printing. 3D printing has an emerging role within medicine and one of its primary benefits for the clinical realm includes the ability to produce patient-specific modeling from de-identified segmented stereolithography (STL) files, as this serves to augment several clinical applications, including trainee simulation [30, 31].

Several 3D-printed models for simulation learning have been tested and positively received by trainees [32-36]. Some studies have found that 3D printed simulations increased student's test scores when studying physiologic [34, 37] and pathologic [38-41] anatomy. 3D printed models have also facilitated groups of dental and surgical trainees in developing better preoperative plans [42,43]. They have been shown to improve simulator procedural performance among anesthesia residents [44] and reduce fluoroscopy and simulator procedural times on endovascular aortic procedures with vascular surgery residents [45-47].

Radiology is well-poised to integrate 3D printing within simulation training. Prototypes, ranging from the lumbar spine to complex vasculature [48-51], have successfully been printed and can be modified for simulation purposes. While the role of three-dimensional printing for trainee education has been documented in other procedural specialties, there is a lack of knowledge about the role of 3D printing for trainee education within IR. Thus, the purpose of this review was to

assess the current prevalence of educational simulation experiences for IR trainees or medical students.

Methods

A literature query was conducted in April 2020 for articles discussing the use of 3D printing in IR simulation experiences via PubMed, Embase, CINAHL, Web of Science, and the Cochrane Library databases. Key search terms included: “3D printing”, “printing, three-dimensional”, “radiology”, “interventional radiology”, “simulation”, “simulation education”, “simulation training”, “simulation learning”, “trainees”, or “student”.

After removing duplicate records, non-English articles, and abstract-only articles, the remaining articles were reviewed. Articles were excluded if they did not feature the use of a 3D printed simulation that was intended for interventional use for trainees, defined as either medical students, diagnostic radiology or interventional radiology residents, or interventional radiology fellows. For combined groups, more than 50% of the participants needed to identify as either medical students, diagnostic radiology or interventional radiology residents, or interventional radiology fellows. Fig. 1 outlines the systematic review.

To assess data quality, studies were evaluated by two reviewers using the Quality Assessment of Diagnostic Accuracy Studies - 2 (QUADAS-2) tool (Fig.2). [52]. The index test was the evaluated 3D printed simulation in each study. The reference standard included a comparison to evaluate the 3D-printed simulation, which could include a pre- and post-assessment, control simulation, or outcomes from a control group. Two independent reviewers appraised these articles.

Results

As noted in Fig. 1, the initial search yielded 843 records and was reduced to a total of 466 after removal of 377 duplicates. Of these, 51 of 466 records were further excluded due to a lack of full-text and availability of the record in English. The majority of excluded articles were original research articles that were not related to 3D printing. Of the 131 articles that discussed 3D printing, 44 of 141 (31.2%) of those articles featured trainee involvement, and 23 of the 44 (52.7%) of these articles featured a 3D printing procedure-oriented simulation. Among the remaining 23 articles, four articles featured our trainee population of interest (i.e. radiology or interventional radiology residents/fellows or medical students) and were included in the review.

All articles reviewed were single institution studies with small sample sizes. The simulated procedures in the aforementioned articles included endoscopic biliary drainage [53], minimally-invasive CT-guided spine procedures [54], and ultrasound guided femoral artery access [55, 56]. Two of the studies analyzed the performance of IR procedures using medical students as the sole test population. Sheu et al. included a randomized assortment of medical students ranging from all years of training (n=49) while Li et al. recruited first- and second-year medical students (n=13). O'Reilly et al. invited a cohort of first year radiology specialist registrars, or physicians in training, (n=19) for their study. Bundy et al. recruited the most diverse test population with varying backgrounds in medicine, including: technologists (n=2), medical students (n=1), residents (n=2), fellows (n=4) with consulting attending physicians (n=2). To evaluate the effectiveness and provide a statistical method of comparison of simulation training using 3D printed materials, each study implemented a distinct approach. The heterogeneity in reported results was the main issue identified by QUADAS-2 assessment, which the reviewers assessed as a low to moderate degree of bias.

In addition to the similarities in the test populations, all four of the studies implemented a pre- and post-test questionnaire that utilized a Likert scale to quantify subjective opinions on 3D printing in IR training. Bundy et al. and Li et al. used a 10-point likert scale to assess the comfort with endoscopic techniques and lumbar punctures respectively. O'Reilly et al. used a 6-point Likert scale to assess the preference between a 3D printed and a commercially available femoral access model of the lower limb in teaching vascular access. Sheu et al. used a five-point likert scale to compare the ease of use, usefulness in practice and student confidence when using a 3D printed and commercially available phantom for femoral artery access.

All four of the studies reported positive feedback regarding the use of 3D printed models for trainee simulation. The comfortability and preference to use 3D printed models for endoscopic training increased in four different procedures as noted in Bundy et al.; however, the only statistically significant results included a 39.7% ($p \leq 0.05$) increase in comfortability performing endoscopic cholecystostomy and a 39.7% ($p \leq 0.05$) increase in the trainee's likelihood to use endoscopy for percutaneous gastrostomy placement. Li et al. showed a significant increase in the confidence in needle stick placement for a control group, which was trained on a 3D model once, and a training group, which was trained on a 3D model twice. The confidence for the control group changed from 1.83 ± 2.0 to 5.8 ± 1.6 with $p \leq 0.004$ while the training group had a change in confidence from 1 ± 0 to 6.1 ± 1.1 with $p \leq 0.00001$. Additionally, there was a significant reduction in the number of needle stick placements for the training group when comparing the initial session, 8.0 ± 1.3 and the final session, 5.4 ± 1.5 , with $p \leq 0.005$. The study further associated a 4.5 mGy-cm reduction of dose with a reduction of 3 needle readjustments, which correlates to a decreased reduction of radiation dose for the training group.

The preference to use the 3D printed model over a commercially available model for femoral artery access training was noted in O'Reilly et al. with an average rating of 5.1 out of 6. Sheu et al.'s results demonstrated that the majority of students in both the 3D printed ultrasound compatible vascular access model (3DPVAM) and commercial model (CM) groups agreed or strongly agreed that the models were useful for practice (96.2% and 95.7%, respectively; $p \leq 0.87$). Student confidence in performing femoral artery access increased by 2 Likert points in both trainee groups. Additionally, there was no difference in the average confidence change when comparing the training experience using the 3D printed model and the commercially produced model ($p \leq 0.001$).

Discussion

A recent needs-assessment survey prioritized the development of ultrasound-guided or interventional procedures for simulation-based training [56]. Contrary to aforementioned evidence of existing IR simulators [10, 13-18, 19], interventional-based simulations remain one of the least common training opportunities available [6]. A survey conducted by Matalon et al. found that 40% of radiology residents do not use simulations as part of their procedural training [6]. The limited number of available articles that features three-dimensional printing in IR simulation training highlights this area of unmet need within radiology training. While it is possible that we missed a relevant study for our review, this limitation was minimized by using free text and MeSH terms across multiple databases. The only articles we did not review were ones that either had no full-text article or were a non-English article, which comprised a minority ($51/466=10.9\%$) of our excluded articles.

There is a lack of quantitative or validated simulation measures. Simulators may not always be able to decipher between experienced or novice operators [57, 58] and must be educationally

validated to be useful. Mechanisms for validation include: face validity, content validity, concurrent validity, discriminant validity, and predictive validity, defined in Table 1 [60]. While each of our studies fulfilled face validity by demonstrating how the simulations appeared under imaging, only Li et al. evaluated content validity in evaluating the students' abilities to complete the intervention (i.e. CT-guided facet block) [54]. Sheu et al. tested concurrent validity by comparing their 3D printed model to the FemoraLineMan CM (Simulab Corp, Seattle, Washington), a commercially available femoral access simulator [56]. This degree of variation in objective feedback raised concerns for a low to moderate degree of bias during QUADAS-2 evaluation.

A potential reason for a limited number of validation measures was that the study population was primarily medical students, as opposed to residents or fellows. Medical students' lack of clinical experience compared to residents, fellows, or attendings minimizes confounders when evaluating procedural performance [13, 56]. While each study could circumvent its study population by establishing face validity on appropriate imaging modalities, future studies evaluating 3D printed simulation will require more robust testing with resident and attendings, especially in regard to predictive validity. Current literature regarding predictive validity for preoperative planning is encouraging, as investigators have associated the use of 3D printed simulations or guides with reduced operative times [61,62]. Within simulation literature, this appears to have only been evaluated in audiology trainees for proper hearing-aid placement [63], where trainees who practiced on a 3D printed simulator achieved a higher percentage of proper hearing-aid placement compared to those who practiced on the control model.

A common theme noted between these studies was the reduced production cost of these models compared to commercially available alternatives. The biliary simulation was one of the

cheapest models to produce, costing approximately \$170 for materials, while the lumbar spinal simulation, which required staged printing of bony structures, nerves, and vessels before assembly, was estimated to cost \$5400. Sheu et al.'s femoral access model, with an estimated lifetime of approximately a dozen punctures, cost approximately \$647 for the initial model and \$100 to replace the 3D-printed vessels, in contrast to competitive alternatives, which may cost between \$2,000-\$4,000, with replacement parts costing between \$600 and \$1600 [56]. This, however, does not factor the printer and software costs, which, again, widely varied between studies. Printed models first require segmentation, which can be completed on either free, open-source software or require purchasing high-end modeling software [30], while actual printers can range from \$6,000-\$750,000 [64]. The financial cost and operational resources associated with 3D printing requires funding and institutional support, which may be another factor in the limited number of simulation articles for IR-related procedures. However, despite upfront investment, these costs can be shared across a hospital, and its resources, from preoperative modeling, simulations, and patient education, are applicable within multiple specialties [30, 31].

Conclusion

Available literature, while supportive of the use of 3D-printing within vascular surgery, cardiology and for procedures performed by non-radiological specialties, is sorely lacking for interventional radiology. The paucity of literature regarding 3D-printing for simulation learning within IR reveals an essential area of improvement in medical education curricula. A lack of objective outcomes hinders advancements in simulation learning, to the disadvantage of trainees. Subsequent research and standardization of 3D-printed simulated experiences can offer more uniform and controlled learning opportunities for trainees to safely refine procedural techniques in the unique field of IR.

Summary of Points

- 3D printing has been utilized as a means of producing high-quality, inexpensive simulation for trainees in procedure-intensive or surgical subspecialties.
- Less is known about its role for trainee education within interventional radiology.
- Our search identified a scarcity of published sources that appraised the use of three-dimensional printing for simulation training in IR where a total of four articles were found.
- Presently available literature endorses the use of three-dimensional printing within interventional radiology as a teaching tool. However, its implementation is largely anecdotal.
- Further research and integration of 3D-printed simulations into IR medical training can help develop and expand this field to a great extent.

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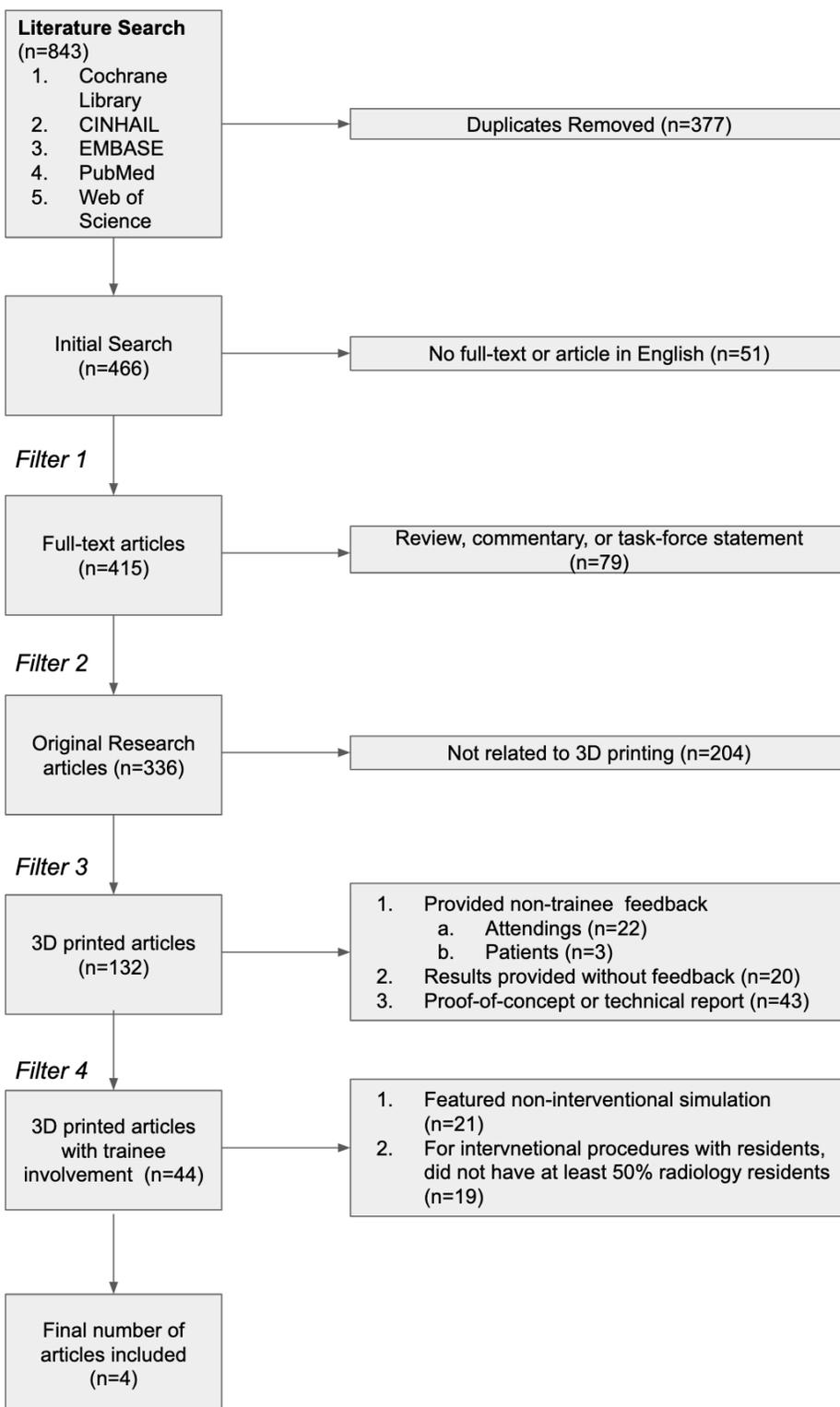


Fig. 1 - Systematic review flowchart.

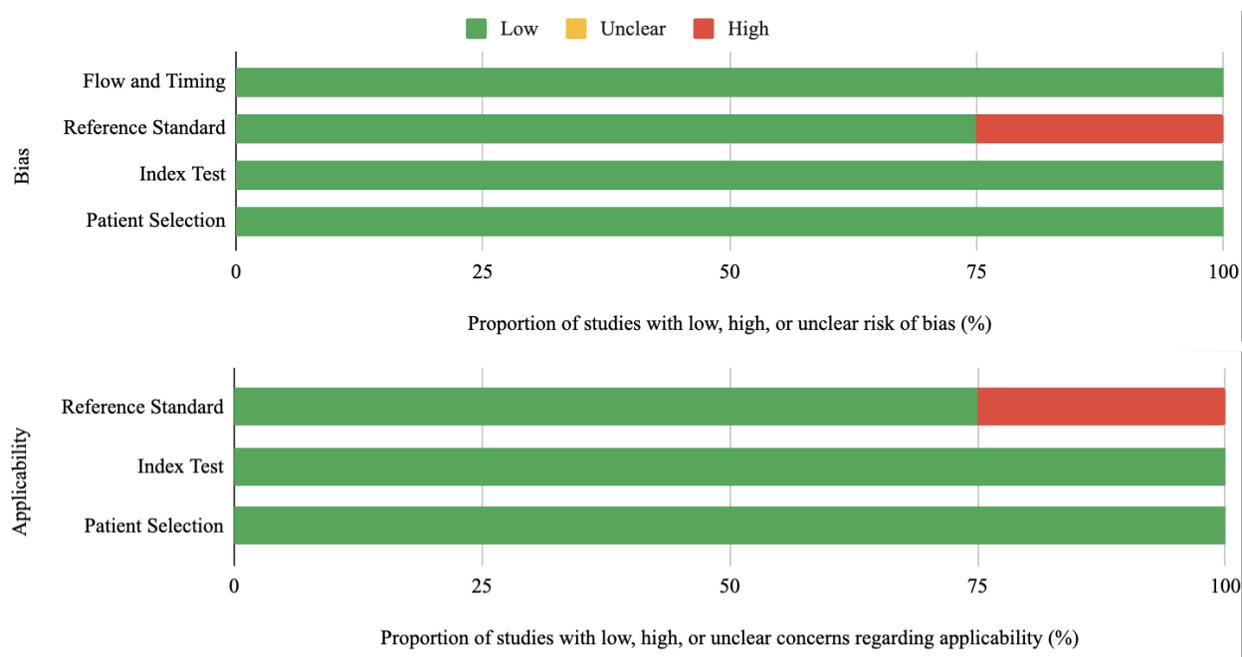


Fig. 2 - Summary of Quality Assessment of Diagnostic Accuracy Studies - 2 (QUADAS-2) ratings. The index test was the evaluation of the 3D-printed simulator. Applicability refers to appropriateness of the simulation to measure trainee ability. The reference standard was a comparison to evaluate the 3D-printed simulation. Flow and timing refers to equal treatment among participants and appropriate study follow-up, if applicable. There was a low to moderate degree of bias established due to the variability between study designs in the reviewed articles.

Type of Validity	Definition
Face validity	Measures the extent that the simulation represents its real-life model
Content validity	Measures the ability for the model to meet its training objectives
Concurrent validity	Compares the model to gold standards in ability to measure the same behaviors
Discriminant validity	Discerns the ability for a model to produce results different from another validated test (if it is intended to do so)
Predictive validity	Evaluates if the simulator accurately or positively correlates with performance in a non-simulated environment

Table 1 - Measures of validity and their definitions for simulation-models.

Declarations

Ethics approval and consent to participate: Not applicable

Consent for publication: Not applicable

Availability of data and materials: Not applicable

Competing interests: Not applicable

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Figures

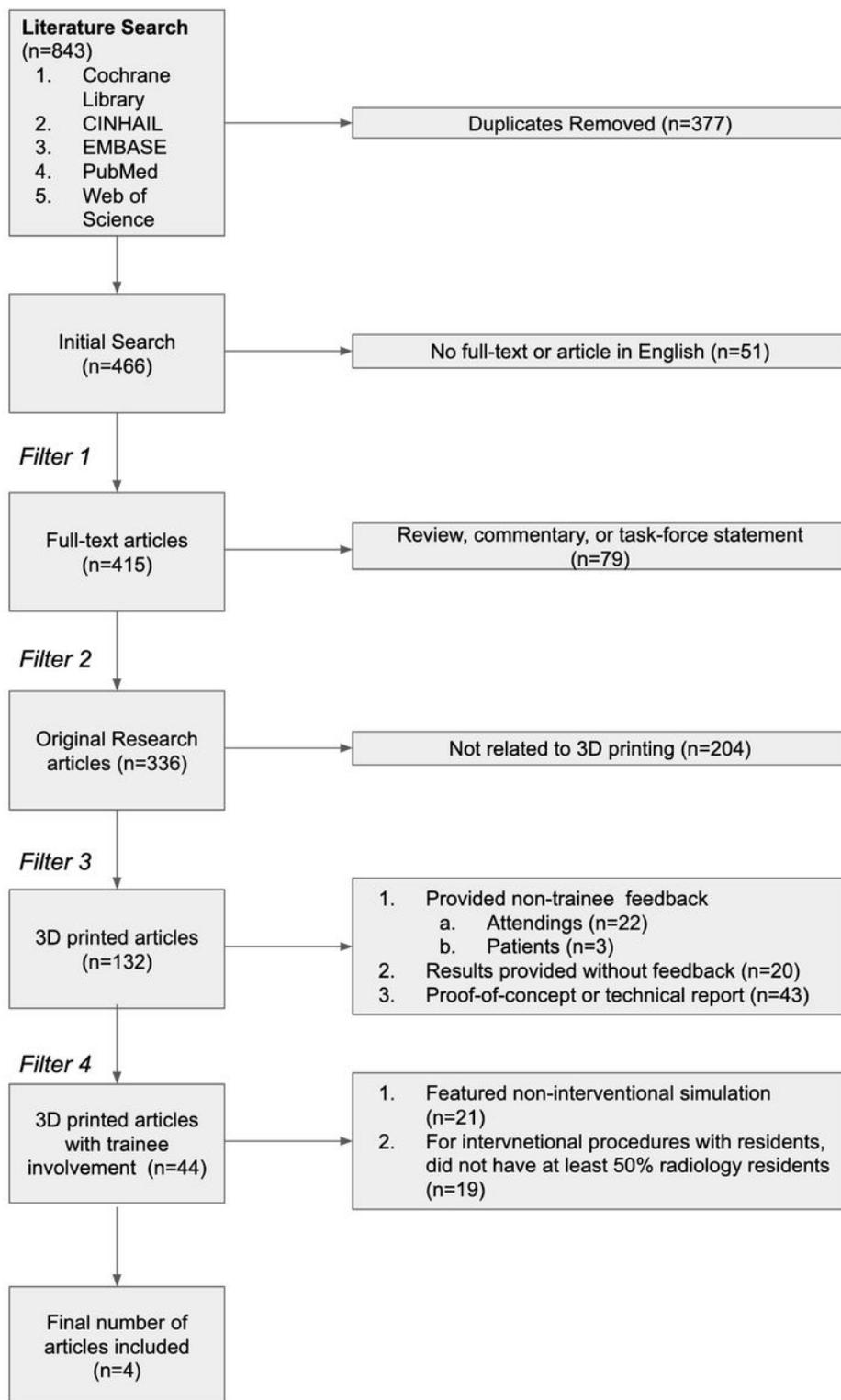


Figure 1

Systematic review flowchart.

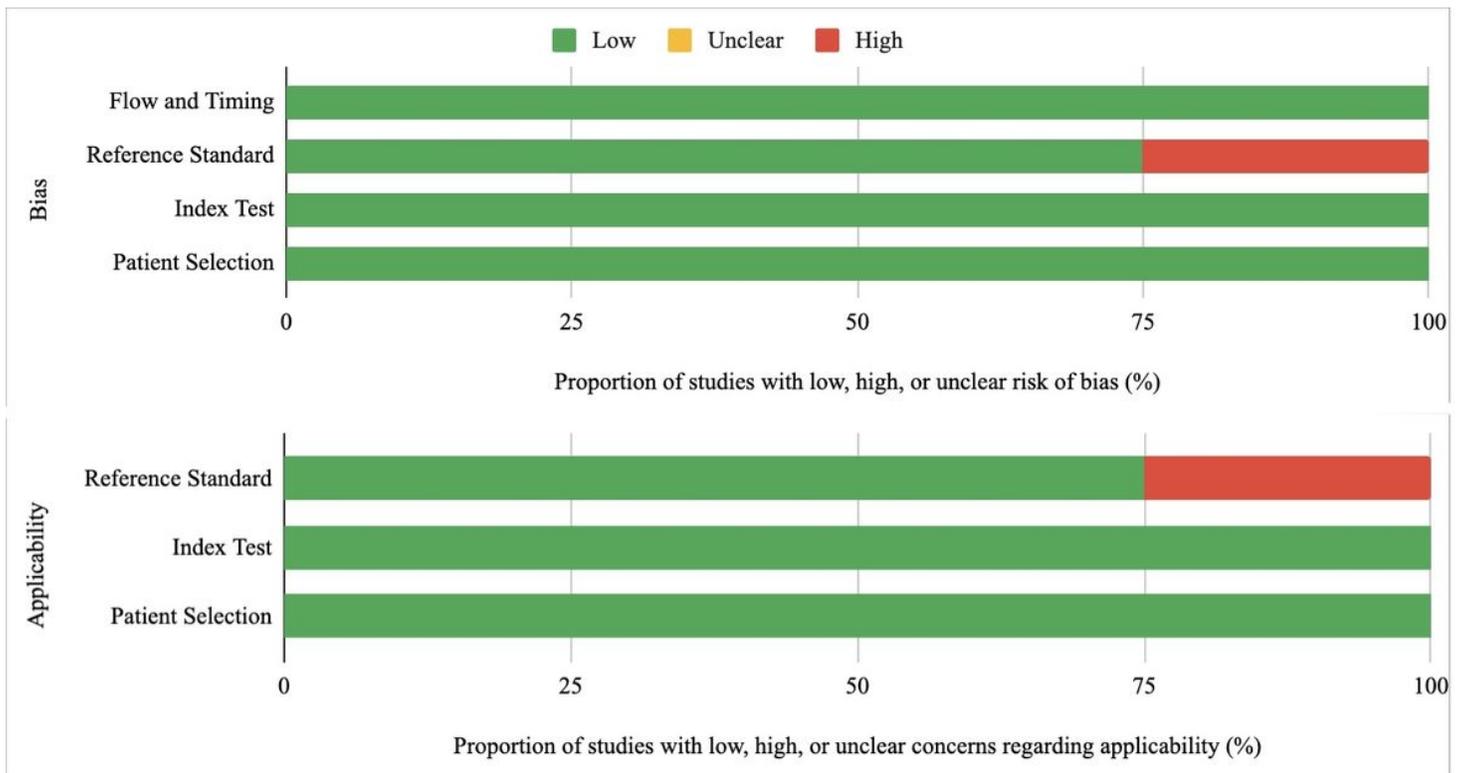


Figure 2

Summary of Quality Assessment of Diagnostic Accuracy Studies - 2 (QUADAS-2) ratings. The index test was the evaluation of the 3D-printed simulator. Applicability refers to appropriateness of the simulation to measure trainee ability. The reference standard was a comparison to evaluate the 3D-printed simulation. Flow and timing refers to equal treatment among participants and appropriate study followup, if applicable. There was a low to moderate degree of bias established due to the variability between study designs in the reviewed articles.