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Enhancing Preclinical Proficiency in Aesthetic Medicine and Cosmetic Dermatology: An Evidence-Based Review of Interactive Visual Simulation Techniques

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ABSTRACT

Background: Unlike many clinical disciplines where simulation is already embedded in curricula, aesthetic medicine and cosmetic dermatology present distinctive training challenges. Interactive visual simulation techniques offer immersive, risk-free environments for developing technique-dependent competencies, but their evidence base within this specific field remains comparatively limited.

Aims: To identify the key features and potential value of interactive visual simulation techniques for aesthetic medicine and cosmetic dermatology, and to provide evidence-based insights for integrating these technologies into academic training programs.

Methods: An evidence-based review using the Best Bets methodology was conducted. Two independent reviewers searched PubMed and Google Scholar (October 2024–February 2025) for literature published between 2015 and 2025. Evidence was graded using the Oxford Centre for Evidence-Based Medicine (OCEBM) 2011 Levels of Evidence, and quality was assessed using Critical Appraisal Skills Programs (CASP) checklists.

Results: Thirteen studies met the inclusion criteria, encompassing 897 reported participants across nine simulation modalities: virtual reality ($n = 2$), augmented/mixed reality ($n = 1$), 3D-printed models ($n = 2$), 3D digital simulation ($n = 1$), hands-on simulation ($n = 2$), simulation-based education ($n = 2$), haptic feedback ($n = 1$), smartphone applications ($n = 1$), and AI applications ($n = 1$). Three of the 13 studies were cross-disciplinary (general dermatological suturing, smartphone adoption patterns, and AI-assisted patient education) and were retained as contextual evidence rather than as direct tests of aesthetic-specific training efficacy. Evidence was predominantly low-level: Level II ($n = 2$), Level III ($n = 3$), Level IV ($n = 2$), and Level V ($n = 6$). Risk of bias was high across the majority. Reported outcomes clustered at Kirkpatrick Levels 1–2a (learner satisfaction and confidence), with only one study demonstrating objective skill improvement (Level 2b). Despite these limitations, simulation-based techniques consistently demonstrated potential to improve self-reported procedural knowledge and trainee confidence.

Conclusion: Simulation-based training shows promise for aesthetic medicine and cosmetic dermatology. Although favorable outcomes were reported, these were predominantly confidence-based (Kirkpatrick Level 2a) rather than objective skill measures. These results cautiously support integration of simulation technologies into training programs but underscore the urgent need for rigorous, randomized controlled trials with objective competence outcomes to establish long-term efficacy and generalizability.

1 | Introduction

The global demand for nonsurgical aesthetic procedures has risen sharply over the past decade, fundamentally reshaping the landscape of cosmetic dermatology [1]. The International Society of Aesthetic Plastic Surgery (ISAPS) reported approximately 34.9 million surgical and nonsurgical procedures performed by plastic surgeons worldwide in 2023, representing a 40% increase over 4 years, with botulinum toxin injections (8.8 million) and hyaluronic acid filler treatments (5.5 million) as the two most frequently performed nonsurgical interventions; actual global volumes are likely substantially higher when procedures performed by dermatologists, general practitioners, and other providers are included [1]. This accelerating demand driven by social media exposure, improved product safety profiles, and widening demographic uptake, has created an urgent need for training programs that can equip practitioners with the precise anatomical knowledge and refined technical skills these procedures require.

The clinical stakes are considerable. Aesthetic procedures operate in anatomically complex facial regions where the distance between a safe injection plane and a dangerous one can be measured in millimeters [2]. Inadvertent intravascular injection of dermal fillers, for example, can cause tissue necrosis or even visual impairment, and incorrect botulinum toxin placement may produce functional asymmetries that persist for months [2]. Yet the current training paradigm for many aesthetic practitioners remains heavily reliant on didactic instruction followed by supervised clinical practice, an approach that affords limited opportunity for deliberate, repetitive skill rehearsal before real patient contact [3, 4].

Simulation-based training (SBT) offers a compelling alternative by enabling learners to develop and refine both technical and nontechnical skills within controlled, risk-free environments before encountering real patients. In other clinical domains, notably surgery and emergency medicine, simulation has already demonstrated transformative potential; a meta-analysis of simulation in surgical training reported statistically significant improvements in procedural knowledge (50.2%) and technical skill performance across 32 pooled studies [5]. Aggarwal et al. and Kunkler have provided foundational overviews establishing simulation as a core component of patient safety and medical education strategy [4, 6]. Haykal et al. highlighted the emerging relevance of virtual reality (VR) and simulation specifically within cosmetic dermatology, noting the potential for immersive technologies to bridge the gap between theoretical knowledge and clinical application in aesthetic practice [2]. Evidence further suggests that earlier exposure to simulation produces more favorable educational outcomes, supporting the case for embedding these technologies at the preclinical stage [6].

While simulation has been progressively integrated into several clinical specialties, from laparoscopic surgery to emergency medicine, its application specifically within aesthetic medicine and cosmetic dermatology has not been substantially investigated [4, 7]. Aesthetic medicine is centered on nonsurgical procedures requiring precise dose calibration, injection depth selection, and recognition of vascular danger zones; competencies that are, in principle, ideally suited to simulation-based acquisition [3, 4]. The published research in this area exhibits inconsistency in evaluation methodologies, necessitating comprehensive examination [3]. This review aims to address this gap by identifying the key features and potential value of interactive visual simulation techniques, and providing evidence-based insights for integrating these technologies into aesthetic medicine and cosmetic dermatology academic training programs.

2 | Materials and Methods

2.1 | Rationale for Methodology

This evidence-based review employed the Best Bets methodology, which was originally developed for time-sensitive clinical questions in emergency medicine but has since been adopted across specialties for rapid, structured evidence appraisal [8]. The review was not prospectively registered; a systematic review was not considered appropriate given the anticipated low volume of high-quality randomized controlled trials (RCTs) and the diversity of simulation modalities under investigation. Best Bets guided the evidence synthesis and critical appraisal throughout, while PRISMA 2020 guidance was used to inform reporting structure, specifically the search flow diagram and the stepwise reporting of screening decisions.

2.2 | Search Strategy

A comprehensive literature search was performed across two electronic databases: PubMed and Google Scholar (last searched February 28, 2025). The search strategy was developed using a modified PIO (Population, Intervention, Outcome) framework, informed by established bibliometric guidelines (Table 1) [9].

TABLE 1 | Three-part research question (population, intervention, and outcome).

Component	Description
Population	Students and trainees in preclinical stages of training in aesthetic medicine and cosmetic dermatology
Intervention	Interactive visual simulation techniques: VR (virtual reality), AR (augmented reality), mixed reality, 3D-printed models, haptic feedback, AI (artificial intelligence) tools, smartphone applications
Relevant outcome	Any reported effect on preclinical performance (procedural knowledge, practical skills, confidence, competence, or safety outcomes)

Note: A formal comparator element was not specified because the review sought to capture any evidence of simulation effect on preclinical performance, whether measured against baseline, traditional instruction, or no comparator (File S1 Section A).
Abbreviations: 3D = three-dimensional, AI = artificial intelligence, AR = augmented reality, VR = virtual reality.

Keywords and MeSH terms were combined with Boolean operators (AND, OR). The full PubMed search string was: ((“virtual reality”[MeSH] OR “augmented reality” OR “simulation training” OR “3D printing” OR “haptics” OR “HoloLens” OR “artificial intelligence”[MeSH]) AND (“aesthetic medicine” OR “cosmetic dermatology” OR “botulinum toxin” OR “dermal filler” OR “cosmetic procedures”) AND ("education" OR “training” OR “simulation” OR “preclinical”)). Google Scholar was searched using four query combinations, each sorted by relevance: (1) “virtual reality” AND “aesthetic medicine training”; (2) “simulation-based training” AND “cosmetic dermatology”; (3) “3D printing” AND “botulinum toxin simulation”; (4) “augmented reality” AND “dermal filler training.” For each query, the first 200 results (20 pages at 10 results per page) were screened by title; potentially relevant titles were then screened by abstract. Google Scholar results were de-duplicated against PubMed records using title and first-author matching. Truncations captured word variations. Limits were applied for human studies and English language. Included studies were published between 2015 and 2025.

2.3 | Study Selection

Study selection was performed by two independent reviewers, with a third reviewer resolving disagreements. No automation tools were used during the screening process; all records were screened manually. Inclusion criteria required original studies on human subjects (RCTs, cohort, cross-sectional, observational, and case series), published in English, investigating interactive visual simulation for enhancing preclinical proficiency in aesthetic medicine or cosmetic dermatology. The primary outcome sought was any reported effect on preclinical performance. A secondary inclusion pathway permitted review articles and conceptual papers to be retained as contextual (Track B) evidence where they provided unique contributions to the understanding of simulation in aesthetic training not available from primary studies; such studies were classified as Level V and are clearly distinguished from primary empirical evidence throughout synthesis. Track A comprises primary studies reporting empirical training outcomes with pre/post measures of skill, knowledge, or confidence. Exclusion criteria comprised: non-English studies; abstracts, case reports, letters, dissertations, and book chapters; studies without available full text; animal or in vitro studies; and studies focused solely on patient education or clinical outcomes rather than trainee proficiency.

Three additional studies were retained despite originating from broader clinical contexts (general dermatological suturing, cross-disciplinary smartphone use, and AI-assisted patient education respectively). These were included as enabling or contextual evidence because they address transferable training principles (psychomotor skill acquisition via simulation), digital adoption patterns relevant to platform design, and AI's emerging role in dermatological education, topics for which no aesthetic-specific primary studies were identified. Their retention is transparently acknowledged as a scope concession; where findings are discussed, the cross-disciplinary origin is noted and claims are appropriately qualified. Readers should interpret evidence from these studies as indicative of broader trends rather than direct evidence for aesthetic-specific training efficacy [10–12].

2.4 | Data Extraction and Synthesis

Data from the final included studies were independently extracted by two reviewers, using a standardized extraction form and organized into evidence tables (File S1 Section B). Extracted variables included: study design, country of origin, participant characteristics (number, training stage, and discipline), simulation modality, outcome measures, follow-up duration, and reported limitations. Studies were grouped by simulation techniques to enable comparison within and across modalities. Reported outcomes were mapped against the Kirkpatrick four-level model for evaluating training program effectiveness (Level 1: learner reaction/satisfaction; Level 2a: change in attitudes/confidence; Level 2b: skill acquisition; Level 3: behavioral change in clinical practice; and Level 4: patient outcomes/organizational impact), which was selected for its widespread adoption in medical education research [13]. Table 2 presents study characteristics including level of evidence, sample size, follow-up duration, main outcomes, and study limitations for each included study.

2.5 | Quality Assessment and Risk of Bias

Methodological quality and risk of bias were assessed by two independent reviewers using CASP checklists appropriate to each study design. Evidence was graded using the OCEBM 2011 Levels of Evidence: Level I (systematic reviews of RCTs); Level II (individual RCTs or quasi-experimental trials with comparator groups); Level III (non-randomized comparative or single-group prospective studies); Level IV (case series/single-group observational studies); and Level V (expert opinion, narrative reviews, conceptual or technical feasibility papers) [14]. The OCEBM framework was selected for consistency with the Best Bets methodology and because it is the most widely recognized evidence-grading system in the target readership. It is acknowledged that OCEBM was designed primarily for therapeutic questions and that education-specific appraisal tools, such as the Medical Education Research Study Quality Instrument (MERSQI) or Best Evidence in Medical Education (BEME) criteria, may offer more granular assessment of educational study quality. Conflicts and disagreements were resolved by a third reviewer through consensus discussion.

3 | Results

3.1 | Study Selection

The initial search identified 2500 records from two databases (PubMed: $n = 1247$; Google Scholar: $n = 1253$). Following removal of 100 duplicate records, 2400 unique records were screened by title and abstract. Of these, 2380 were excluded (irrelevant population, intervention, or outcome: $n = 1820$; non-English language: $n = 245$; review articles, book chapters, letters, or conference proceedings: $n = 198$; animal or in vitro studies: $n = 117$). Twenty reports were sought for retrieval, of which two could not be obtained

TABLE 2 | Study characteristics, level of evidence, and outcomes.

Technique	Study	LoE	*n*	Follow-up	Main outcome	Study limitations
SBE	Hassan et al. (2025), UK	IV	25	N/A	Interactive 3D app improved proficiency and confidence in aesthetic medicine preclinical training	Small sample; single institution; no control group; no long-term follow-up
VR	Stavrianoudaki et al. (2022), Greece	V	N/A	N/A	VR environments engage students through immersive experiences; theoretical benefits of full-immersion systems described	Conceptual; no empirical data; cost and simulator sickness concerns noted
3D/MR (HoloLens)	Kumar et al. (2021), UK	V	12	NR	HoloLens-based virtual face depicted facial anatomical layers with robust inter-rater reliability	Small sample; limited mesh density; no training outcome data
SBE	Elendu et al. (2024), Nigeria	V	N/A	N/A	SBT improves skill development, reduces errors, allows repeated practice without patient risk	Narrative review; no original empirical data
3D-Printed (Botox)	Tabaru et al. (2024), Turkey	III	30	1, 3, and 6 months	3D-printed models increased confidence and knowledge in botulinum toxin application; improvements sustained at 6 months	Single-group; no control for simulation component specifically
Hands-on (Botox)	Mitkov et al. (2018), USA	II	20	Immediate posttest	Significantly higher practical scores in simulation group vs. video instruction; no difference in comfort or knowledge	Small sample; cadaver models; no long-term follow-up
Smartphone	Grow et al. (2019), USA	III	577	Cross-sectional	99.3% owned smartphone; digital use exceeded print; 82.1% knew < 10 relevant apps; largest survey of digital resource adoption in aesthetic training	Survey-based; no performance outcomes; cross-disciplinary sample
3D Digital Simulation	Rao et al. (2023), China	V	NR	Technical feasibility only	3D structured-light scanning enables personalized facial simulation planning with less error than 2D methods	Technical feasibility only; no training outcomes reported
Haptic Feedback	Kim (2016), Korea	V	12	Single experiment	Visuohaptic rendering improved detection of skin irregularities vs. visual-only assessment	Lab setting; small sample; not training-focused
VR (Filler)	Oh et al. (2020), Korea	IV	100	Single session	VR filler training system demonstrated feasibility; users rated system favorably for 3D anatomical visualization and vascular danger zone identification	No comparator; usability data only; no training outcome measures
Hands-on vs. Video	Alshaalan (2022), Saudi Arabia	II	81	Pre/post (immediate)	Hands-on simulation increased suturing confidence vs. video instruction	No long-term follow-up; single institution; confidence measure only (Kirkpatrick 2a)

(Continues)

TABLE 2 | (Continued)

Technique	Study	LoE	*n*	Follow-up	Main outcome	Study limitations
AI	Herrick et al. (2024), USA	V	N/A	N/A	AI tools enhance patient education, engagement, and adherence in dermatological care	Review; no original empirical training data
3D-Printed (Fillers)	Tabaru et al. (2024), Turkey	III	40	Pre/post (immediate)	Significant improvement in procedural understanding, confidence, and self-reported competence ($p < 0.001$); participant-reported measures only (Kirkpatrick 2a)	No control group; single session; no long-term data

Note: Kumar et al. 2021 was classified as Level V because the study was a technical feasibility report demonstrating inter-rater reliability of a HoloLens-based anatomical visualization among 12 specialists, without empirical training outcomes (no pre/post knowledge, skill, or confidence measures). By contrast, Grow et al. 2019 was classified as Level III as a cross-sectional comparative survey of digital resource adoption in 577 participants, providing population-level descriptive data relevant to platform design even though it did not report training outcomes.
Abbreviations: 3D = three dimensional, AI = artificial intelligence, AR = augmented reality, Botox = botulinum toxin, LoE = level of evidence, MR = mixed reality, N/A = not applicable, *n* = number of participants, NR = not reported, SBE = simulation-based education, VR = virtual reality.

(full text unavailable). Eighteen reports were assessed for eligibility; five were excluded (focused on patient outcomes rather than trainee proficiency: $n = 2$; duplicate dataset: $n = 1$; review or editorial: $n = 1$; insufficient methodological quality: $n = 1$). Thirteen studies met all inclusion criteria [3, 7, 10–12, 15–22]. Figure 1 presents the PRISMA 2020 flow diagram. File S1 Section A provides the PRISMA search and complete screening log.

3.2 | Characteristics of Included Studies

The 13 included studies were published between 2016 and 2025, originating from eight countries across four continents (United States: $n = 3$; Turkey: $n = 2$; Korea: $n = 2$; United Kingdom: $n = 2$; Greece: $n = 1$; Nigeria: $n = 1$; Saudi Arabia: $n = 1$; China: $n = 1$), reflecting the global reach of both aesthetic medicine practice and educational innovation. Study designs comprised two Level II studies [12, 17], three Level III studies [10, 16, 21], two Level IV studies [20, 22], and six Level V studies [3, 7, 11, 15, 18, 19]. Total participants across the nine studies reporting sample sizes was 897 (range 12–577; median approximately 30); four studies did not report individual participant numbers as they were conceptual, narrative, or technical feasibility investigations [3, 7, 11, 18]. The considerable range in sample sizes, from 12 in a laboratory haptics study to 577 in a cross-sectional survey, reflects the methodological heterogeneity of this emerging field. Under the secondary inclusion pathway, two review articles were retained as Track B contextual evidence because they provided unique conceptual contributions directly relevant to simulation in aesthetic training not available from primary research studies [3, 11]; these are classified as Level V and carry the lowest evidence grade.

Table 2 summarizes individual study characteristics. File S1 Section C provides completed data extraction summaries for all 13 included studies.

3.3 | Summary of Findings by Simulation Modality

3.3.1 | 3D-Printed Models and 3D Digital Simulation

Two 3D-printed model studies and one 3D digital simulation study together provided the most directly relevant evidence in this review. Tabaru et al. reported that 3D-printed facial models increased confidence and knowledge in botulinum toxin application among 30 participants in a single-group prospective observational study, with improvements sustained across assessments at 1, 3, and 6 months post-training, the longest follow-up period of any included study (Level III) [16]. Tabaru et al. reported significant improvement in procedural understanding, confidence, and self-reported competence for facial filler training in 40 participants ($p < 0.001$; Level III) [21]. The competence measure was participant-reported on a structured scale rather than objectively assessed, and therefore maps to Kirkpatrick Level 2a (change in attitudes/confidence) rather than Level 2b (demonstrated skill acquisition); Mitkov et al. remains the only included study providing Level 2b evidence through blinded practical scoring [17]. These models offer considerable practical advantages: they are relatively low-cost, easily reproducible using consumer-grade 3D printers, and require no specialized digital infrastructure or software licensing. For training

programs with limited budgets, they represent the most immediately accessible simulation modality.

A related but distinct approach was reported by Rao et al., who demonstrated that 3D structured-light scanning enables personalized facial simulation planning with less error than conventional 2D methods (Level V) [15]. While this study focused on technical feasibility rather than training outcomes, it illustrates the potential of 3D digital simulation to support individualized procedural planning in aesthetic contexts; a direction that could, if integrated with training platforms, allow trainees to practice on patient-specific facial topographies before performing actual procedures.

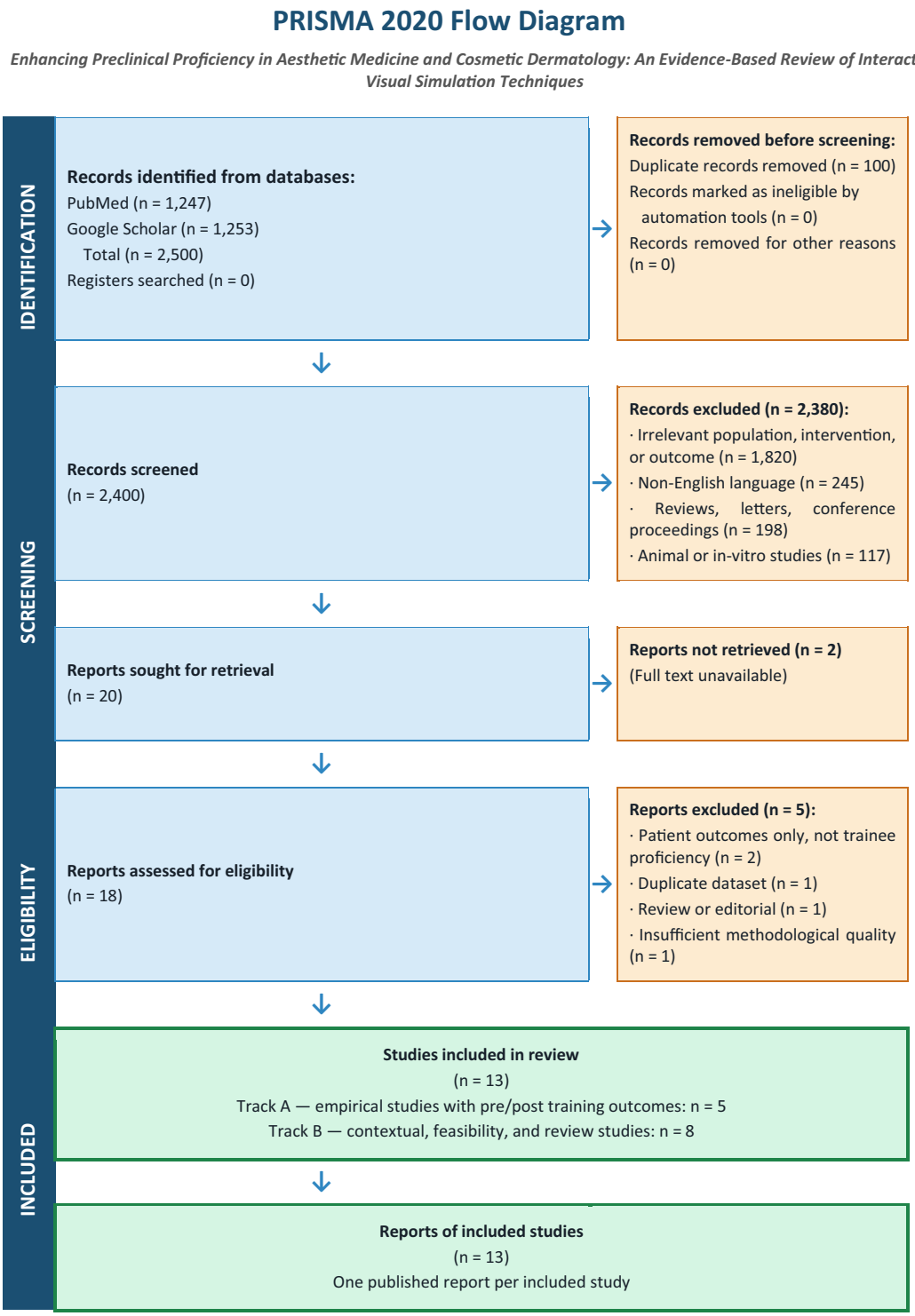

FIGURE 1 | PRISMA 2020 flow diagram.

#	Yellow box	PRISMA 2020 Guidance (original yellow text)	Resolution applied in revised diagram	Impact on paper
1	* (single asterisk) Identification box	"Consider, if feasible to do so, reporting the number of records identified from each database or register searched (rather than the total number across all databases/registers)."	FEASIBLE — per-database numbers ARE available from the paper. The Identification box now reads: "PubMed (n = 1,247) • Google Scholar (n = 1,253) • Total databases (n = 2,500) • Registers (n = 0) — no registers searched the yellow guidance note is thereby fully satisfied and can be removed from the final figure.	Section 2.2 of paper already states both numbers. No change to paper text needed — only the figure updated.
2	** (double asterisk) "Records removed before screening" box	"If automation tools were used, indicate how many records were excluded by a human and how many were excluded by automation tools."	NO automation tools were used. Section 2.3 of the paper states: "Study selection was performed by two independent reviewers, with a third reviewer resolving disagreements." This is entirely manual. The "Records removed before screening" box now explicitly states: Automation tools used: NO — manual only • Records marked as ineligible by automation tools (n = 0) The yellow guidance note is fully resolved; no ambiguity remains.	Minor clarification added to Section 2.3 to make the absence of automation tools explicit, reinforcing the manual review process.

FIGURE 1 | (Continued)

3.3.2 | Hands-On Simulation

Two studies examined hands-on simulation and both produced Level II evidence. Mitkov et al. demonstrated significantly higher practical scores in the simulation group compared with video instruction for cosmetic botulinum toxin injection in 20 participants, though notably no difference was observed in comfort or knowledge scores, suggesting that simulation's primary advantage lies in technical skill acquisition rather than cognitive learning (Level II) [17]. Alshaalan confirmed that hands-on simulation increased suturing confidence compared with video instruction in 81 preclinical medical students, the second-largest sample among the comparative studies (Level II) [12]. Together, these findings suggest that for the specific psychomotor demands of aesthetic procedures (needle placement, depth control, injection technique), hands-on engagement produces measurably superior outcomes compared with passive observation.

3.3.3 | Virtual and Augmented Reality

Three studies addressed VR or AR technologies, spanning a spectrum from theoretical conceptualization to practical usability testing. Stavrianoudaki et al. provided a conceptual overview of VR environments in aesthetics education, arguing that full-immersion

systems could offer unparalleled engagement but noting important barriers including cost, hardware requirements, and the risk of simulator sickness (Level V) [7]. Kumar et al. demonstrated that a HoloLens-based virtual face depicted facial anatomical layers with robust inter-rater reliability among 12 specialists, offering a proof of concept for mixed reality in facial anatomy education, though no training outcomes were reported (Level V) [15]. Oh et al. developed the most clinically advanced VR-based system, a filler injection training platform, and demonstrated usability among 100 participants; users rated the system favorably for anatomical visualization and vascular danger zone identification, though no training outcomes (knowledge or skill gains) were assessed (Level IV) [20]. Recent work by Muralidharan et al. has outlined best practices for VR/AR research in dermatology, providing a methodological framework that future studies in aesthetic medicine simulation should adopt [23].

3.3.4 | Simulation-Based Education (SBE)

Two studies examined broader SBE frameworks. Elendu et al. conducted a narrative review concluding that SBT improves skill development, reduces errors, and allows repeated practice without patient risk. These benefits are particularly relevant in aesthetic medicine, where the consequences of procedural error are often immediately visible and personally distressing for patients (Level V) [3]. Hassan et al. demonstrated that an interactive 3D simulation application improved proficiency and confidence among 25 healthcare professionals enrolled in aesthetic medicine postgraduate training (Level IV) [22]. This study is notable as one of few to have been conducted within a dedicated aesthetic medicine program, rather than a general dermatology or interdisciplinary setting, lending it particular relevance to the aims of this review.

3.3.5 | Haptic Feedback, Smartphone Applications, and AI

Each modality was represented by a single study, reflecting its early-stage development. Kim demonstrated that visuohaptic rendering improved detection of skin irregularities compared with visual-only assessment in 12 participants (Level V) [19]. While conducted in a laboratory setting rather than a clinical training environment, this study points toward a potentially transformative application: haptic simulation could allow trainees to develop the tactile discrimination that experienced practitioners use to assess tissue depth, injection resistance, and product placement; skills that are currently acquired only through extensive clinical experience.

Grow et al. surveyed 577 participants on smartphone application use in aesthetic and reconstructive contexts, reporting that 99.3% owned a smartphone and digital resources exceeded print use, though no performance outcomes were assessed (Level III) [10]. While this study drew from a cross-disciplinary sample, it was retained as the only investigation addressing digital resource adoption patterns in aesthetic training. This is an important contextual consideration for future simulation design, given that mobile platforms represent the most accessible route to widespread training tool deployment. Herrick et al. reviewed the role of AI tools in enhancing patient education and engagement in dermatological care but presented no original empirical training data (Level V) [11].

3.4 | Risk of Bias Summary

Risk of bias was high across the majority of included studies, a finding that tempers the otherwise encouraging outcome data. Common sources included absence of randomization (10/13), lack of blinding (12/13), no control group (8/13), small sample sizes (9/13 had $n < 100$), immediate posttest only with no long-term follow-up (11/13), and failure to pre-define or report adverse events (10/13). Selective outcome reporting was prevalent, with studies predominantly reporting favorable results. No study employed an intention-to-treat analysis, and attrition data were inconsistently reported. Table 3 provides a structured risk of bias summary for all included studies. File S1 Sections D–F show the individual quality appraisal summaries for all 13 studies (item-by-item), notes explaining the rationale for each appraisal tool used, and a cross-validation note ensuring File S1 reproduces the corresponding statement in the main manuscript.

4 | Discussion

4.1 | General Interpretation

This review identified 13 studies examining interactive visual simulation techniques for preclinical training in aesthetic medicine and cosmetic dermatology. The body of evidence, while consistently suggesting potential benefits, must be interpreted with considerable caution given the predominantly low level of evidence (Level IV–V in 8/13 studies) and pervasive risk of bias. Notably, no Level I evidence (systematic reviews of randomized controlled trials) exists for simulation in aesthetic medicine and cosmetic dermatology. This is a critical knowledge gap that is particularly striking given the global scale of aesthetic practice and the patient safety implications of inadequate training. This absence underscores the contribution of the present review as a first attempt to consolidate the available evidence in this field.

To facilitate interpretation, the 13 included studies can be categorized into two tracks. Track A comprises five studies reporting empirical training outcomes with pre/post measures of skill, knowledge, or confidence [12, 16, 17, 21, 22]. Track B comprises eight enabling, feasibility, usability, survey, or conceptual studies that provide contextual evidence without pre/post training outcome data [3, 7, 10, 11, 15, 18–20]. Conclusions regarding simulation effectiveness are drawn primarily from Track A; Track B studies contextualize the technological landscape, adoption patterns, and system feasibility but do not constitute evidence of training efficacy.

When Track A outcomes are mapped against the Kirkpatrick four-level evaluation framework, widely used in medical education research [13], a notable pattern emerges. The majority of reported outcomes cluster at Level 1 (learner reaction/satisfaction) and Level 2a (change in attitudes/confidence). Only Mitkov et al. provided evidence at Kirkpatrick Level 2b (acquisition of knowledge/skill) through objective practical

TABLE 3 | Risk of bias and methodological quality summary.

Study	Randomisation	Blinding	Control group	Sample size	Long-term follow-up	Outcome pre-defined
Hassan et al. (2025)	No	No	No	Small (25)	No	Partial
Stavrianoudaki et al. (2022)	N/A (Level V)	N/A	N/A	N/A	N/A	N/A
Kumar et al. (2021)	N/A (Level V)	No	No	Small (12)	No	N/A
Elendu et al. (2024)	N/A (Level V)	N/A	N/A	N/A	N/A	N/A
Tabaru et al. (2024a)	No	No	No	Small (30)	Yes (6 months)	Partial
Mitkov et al. (2018)	Yes	No	Yes	Small (20)	No	Yes
Grow et al. (2019)	No	No	No	Large (577)	No	Yes
Rao et al. (2023)	N/A (Level V)	No	No	N/A	N/A	N/A
Kim (2016)	N/A (Level V)	No	No	Small (12)	No	N/A
Oh et al. (2020)	No	No	No	Moderate (100)	No	No
Alshaalan (2022)	Yes	No	Yes	Moderate (81)	No	Yes
Herrick et al. (2024)	N/A (Level V)	N/A	N/A	N/A	N/A	N/A
Tabaru et al. (2024b)	No	No	No	Small (40)	No	Partial

Note: Green = low risk; Red = high risk; Amber = partial; Grey = not applicable (Level V conceptual/review studies).

scoring [17]. No study assessed Kirkpatrick Level 3 (behavioral change in clinical practice) or Level 4 (patient outcomes/organizational impact). This distribution is important because self-reported confidence (Level 2a) does not reliably predict clinical competence, which is a distinction well-established in medical education literature. The predominance of confidence-based outcomes means that, despite consistently positive findings, the evidence that simulation actually improves what trainees can do (rather than how they feel about what they can do) remains thin. Future studies should prioritize objective competence measures, such as blinded expert assessment of procedural performance, Objective Structured Clinical Examination (OSCE) stations, or validated assessment instruments specific to aesthetic procedures.

The strongest evidence supports 3D-printed models and hands-on simulation. Mitkov et al. demonstrated significantly higher practical scores with simulation than video instruction for botulinum toxin injection technique [17]. Alshaalan confirmed that hands-on simulation increased suturing confidence compared with video [12]. Tabaru et al. reported significant improvements in procedural understanding, confidence, and self-reported competence following 3D-printed model training for facial fillers ($p < 0.001$; Kirkpatrick Level 2a measures) [21]. Hassan et al. demonstrated that interactive 3D simulation applications improve proficiency and confidence in aesthetic medicine preclinical training within a dedicated postgraduate aesthetic medicine program [22].

4.2 | Critical Appraisal of Best Evidence

Even the two Level II studies warrant critical scrutiny. Mitkov et al. employed a very small sample ($n = 20$), assessed outcomes only immediately post-training, and tested on cadaver skin models rather than live patients, limiting ecological validity. A cadaver skin model cannot replicate the tissue resistance, patient feedback, and anxiety management that characterize real clinical encounters [17]. Alshaalan employed a randomized comparative design (hands-on vs. video simulation) with 81 participants, which is methodologically the strongest design among the included studies. However, it measured only self-reported confidence (Kirkpatrick Level 2a) rather than objective suturing performance, was conducted at a single institution with immediate post-training assessment only, and addressed general dermatological suturing rather than aesthetic-specific procedures [12]. Among the Level III studies, Tabaru et al. possesses the longest follow-up (6 months), but it was a single-group prospective observational study without a comparator, meaning that improvements cannot be attributed to the 3D-printed model specifically rather than the broader teaching session or maturation effects [16]. Neither Level II study reported blinding of outcome assessors, and effect sizes were not consistently reported across any included study, making it difficult to determine the clinical meaningfulness of observed differences.

4.3 | Cross-Modality Comparison

Considering the limitations of the available data, 3D-printed models emerged as the most evidence-supported approach, with two studies reporting improvements in both knowledge and confidence while offering low-cost, reproducible advantages requiring no specialized infrastructure [16, 21]. For resource-constrained training programs, this modality presents the lowest barrier to adoption. Hands-on simulation similarly produced strong evidence of skill improvement and is

readily integrated into existing curricula [12, 17]. By contrast, VR and AR technologies, while conceptually promising and gaining traction in dermatology more broadly [2, 23], were represented only by feasibility and usability studies without controlled outcome data; they also carry higher costs, require technical support infrastructure, and present known issues such as simulator sickness [7, 20]. 3D digital simulation showed technical promise for personalized facial planning but has not yet been evaluated as a training tool [18]. Haptic feedback and AI applications remain at the earliest stages of development, with evidence limited to laboratory demonstrations and narrative reviews [11, 19].

On balance, the current evidence favors low-cost, high-fidelity tangible approaches for immediate curricular integration. However, it would be premature to dismiss emerging technologies: the trajectory of VR costs has been steeply downward, and the integration of AI-driven feedback into simulation platforms could eventually deliver personalized, adaptive training experiences that static models cannot. The field should pursue parallel investment in both proven and emerging modalities.

4.4 | Generalizability

A critical consideration is the generalizability of these findings. Most included studies originated from multidisciplinary contexts (general dermatology, biomedical engineering, or medical education) rather than dedicated aesthetic medicine or cosmetic dermatology training programs. The skills required for nonsurgical aesthetic procedures, such as botulinum toxin dose calibration, filler injection depth and plane selection, as well as recognition of vascular danger zones, differ substantially from those in other clinical contexts. Alshaalan, for instance, evaluated suturing simulation rather than injectable techniques; while suturing develops transferable psychomotor dexterity, it does not address the aesthetic judgment and three-dimensional facial analysis that are central to injectable procedures [12]. Similarly, Grow et al.'s smartphone survey captured cross-disciplinary digital adoption patterns rather than aesthetic-specific training outcomes [10]. These studies are retained as contextual evidence but their findings should not be interpreted as direct evidence for aesthetic procedure training efficacy. Rehman et al. have argued that nonsurgical facial aesthetics should be formally incorporated into medical education, though the optimal pedagogical approach remains debated [24]. Furthermore, regulatory and professional training pathways for aesthetic medicine practitioners vary considerably across countries (from highly regulated frameworks in the United Kingdom and EU to more permissive environments elsewhere), meaning that simulation tools developed within one educational system may not be directly applicable in another [25].

Geographic clustering of the evidence also warrants attention: three studies originated from the United States, two each from Turkey, Korea, and the United Kingdom, and one each from Greece, Nigeria, Saudi Arabia, and China. The majority were single-institution studies, limiting the external validity of findings. No multicenter studies were identified. This concentration means that the evidence may disproportionately reflect the training cultures, regulatory frameworks, and resource availability of a small number of countries, and findings should be extrapolated to other settings with caution.

Conventional training methods including live demonstrations, model-based practice, and apprenticeship-based learning have recognized limitations: patient safety risks, inconsistent clinical exposure, and the inherent tension between educational needs and patient care demands. The simulation modalities reviewed here have the potential to address several of these deficiencies by providing safe, repeatable, and standardized learning environments that can be accessed outside clinical hours and at the learner's own pace [3, 6].

4.5 | Limitations of Evidence

Study designs ranged from conceptual reviews to small nonrandomized trials. Sample sizes were frequently small (range 12–577, median approximately 30), and several studies relied on self-reported confidence rather than objective performance measurement, which is a distinction that matters critically, since confidence does not reliably predict competence (Kirkpatrick Level 2a vs. 2b). The majority of positive outcomes in this review reflect learner satisfaction and attitude change rather than demonstrated skill acquisition or behavioral change in practice. Technologies were disparate without device-specific comparisons. The predominance of Level IV/V evidence, reliance on single-group pre–post designs, absence of randomization and blinding, and lack of confounder control (prior experience, instructor variability, test–retest effects) compromise internal validity. Selective benefit reporting and absent long-term follow-up threaten generalizability. The complete absence of Level I evidence means that no meta-analytic conclusions can be drawn, and all findings should be regarded as preliminary.

4.6 | Limitations of the Review

The use of Best Bets rather than full systematic review limits its synthesis rigor. Only two databases (PubMed and Google Scholar) were searched; EMBASE, CINAHL, Cochrane Library, and Web of Science were not included, meaning that relevant studies indexed only in those databases may have been missed. English-language restriction introduces potential selection bias, particularly given the global distribution of aesthetic medicine practice and education. Heterogeneity of designs and outcomes precluded meta-analysis. The inclusion of two narrative reviews and several non-aesthetic contextual studies under the Track B secondary pathway widens the scope of evidence considered; while this is defined as a priori and transparently reported, it represents a broader inclusion strategy than a strictly focused systematic review would permit. The review protocol was not prospectively registered, consistent with the rapid-appraisal design of the Best Bets methodology.

4.7 | Implications for Practice and Future Research

Despite limitations, findings offer preliminary support for integrating SBT into preclinical aesthetic medicine and

cosmetic dermatology programs. Cost-effective modalities such as 3D-printed models for filler and toxin training appear particularly promising for immediate adoption and could feasibly be incorporated into postgraduate curricula within a single academic cycle [16, 21]. The rapidly evolving landscape of VR, AR, and AI in cosmetic dermatology [2, 23, 26] suggests that technology-enhanced training will become increasingly important as hardware costs decline and content platforms mature.

Future research should prioritize large, multicenter RCTs with adequate sample sizes, control groups, standardized outcome measures (ideally combining objective performance assessment with trainee-reported confidence and patient-reported outcomes), long-term follow-up, and predefined adverse event reporting. Device-specific comparisons between modalities (for instance, 3D-printed model vs. VR simulator for the same filler injection task), cost-effectiveness analyses, and the development of validated assessment tools specific to aesthetic medicine simulation training are all urgently needed. The present absence of Level I evidence should be viewed as both a limitation and an opportunity: a well-designed systematic review of RCTs in this field, once sufficient primary data accumulate, would represent a significant contribution to the evidence base and could inform curricular policy internationally.

5 | Conclusion

This review identified 13 studies investigating interactive visual simulation techniques for enhancing preclinical proficiency in aesthetic medicine and cosmetic dermatology. SBT, particularly through 3D-printed models, hands-on simulation, and VR, demonstrates potential to improve trainee confidence and self-reported procedural knowledge. However, only one study provided objective evidence of skill improvement (Kirkpatrick Level 2b), and no study assessed behavioral change in clinical practice or patient outcomes (Levels 3–4). The overall certainty of evidence is low to very low, with the majority of studies being methodologically limited and no Level I evidence available. These results cautiously support simulation integration into training programs but clearly highlight the urgent need for rigorous RCTs with objective competence outcomes to establish long-term efficacy, generalizability, and comparative effectiveness of specific simulation modalities. As the global aesthetic medicine sector continues to expand, the imperative to train practitioners safely before they encounter real patients has never been more pressing.

Author Contributions

Conceptualization and study design, methodology, formal analysis and evidence synthesis, writing – review and editing: All authors. Literature search and screening, writing – original draft, supervision: Hassan Khalil. Data extraction and CASP appraisal: Hassan Khalil, Haidar Hassan, and Ines Novo Pereira to mitigate authorship conflict and resolve disagreements. All authors have read and approved the final version of the manuscript.

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Ethics Statement

This study is a review of published literature and did not involve the collection of new human or animal data. Ethical approval was therefore not required.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **File S1:** Screening log, data extraction template, and individual quality appraisal summaries.