Systematic Review

Plastination in Anatomy Teaching: Comparative Effectiveness Versus Formalin -Fixed Cadavers and Digital/3D Models - An Updated Systematic Review

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Abstract

Background: Plastination, introduced by von Hagens in the late 1970s, represents a significant advancement in the preservation of anatomical specimens. This updated systematic review evaluates the comparative effectiveness of plastinated specimens, formalin-fixed cadavers, and digital/3D models in anatomy education. **Material and Methods:** A comprehensive literature search was conducted using PubMed, Scopus, Embase, Web of Science, ERIC, and CINAHL databases. Studies published from 2010 onward involving medical, dental, allied health, and veterinary students were included. Study quality was assessed using RoB 2 for RCTs and ROBINS-I for non-randomised studies—the Kirkpatrick training evaluation framework guided outcome assessment. **Results:** Twelve studies met inclusion criteria, including randomised controlled trials, quasi-experimental studies, observational cohorts, and systematic reviews. Evidence demonstrates that plastinated specimens produce comparable or superior learning outcomes to formalin-fixed cadavers in knowledge acquisition and spatial understanding. Students consistently reported positive perceptions of plastinated materials, particularly regarding odour elimination, durability, and reduced exposure to hazardous chemicals. Comparative studies with 3D-printed models and digital resources reveal complementary rather than competing educational roles. **Conclusion:** Plastination represents a valuable, evidence-supported adjunct to anatomy teaching. The accumulated evidence supports integrating plastinated specimens with traditional dissection and digital modalities in a multimodal approach, rather than treating them as complete replacements. Future research should prioritise rigorous, adequately powered randomised controlled trials assessing long-term retention and clinical skills transfer.

Keywords: Plastination, Anatomy education, Cadaveric dissection, 3D printing, Medical education, Learning outcomes.

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Introduction

An in-depth understanding of human anatomy is fundamental to medical education and clinical practice. Traditionally, cadaveric dissection and anatomical prosections have served as the gold standard teaching modalities for human gross anatomy, providing essential hands-on experience and spatial comprehension of anatomical structures.[1,2] Nonetheless, several contemporary challenges have emerged in the utilisation of traditional donor-based materials, including scarcity of donated bodies, ethical concerns regarding informed consent and body disposition, increased risk of pathogenic microorganism transmission from cadavers, and significant health hazards associated with formaldehyde exposure during preservation.[1-3]

These limitations have prompted educators worldwide to explore innovative, ethical, sustainable, and safe alternatives for anatomy pedagogy. Among modern methods developed, plastination - a technique introduced by von Hagens in the late 1970s and patented between 1978 and 1982 - has gained substantial global attention.[1,4] Plastination involves replacing tissue fluids and lipids with curable polymers (most commonly silicone S10, epoxy E12, or polyester P40), resulting in durable, odourless, and non-toxic anatomical specimens that do not require specialised refrigeration or hazardous chemical storage.[1,5] This method facilitates easy handling and long-term preservation, making plastinated specimens a practical adjunct or alternative to traditional cadaveric dissection, especially in contexts where cadaver availability is limited or their maintenance is problematic.[1,4]

Plastinated specimens have been used extensively to prepare prosected specimens and transparent body slices, enabling detailed anatomical visualisation and enhanced spatial understanding of structures.[1,5] These specimens have demonstrated utility across medical, dental, veterinary, and allied

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health education, including facilitation of comprehension of complex anatomical regions such as the pelvis, knee, head and neck, and cardiac anatomy.[1,2,5,6] Moreover, plastination offers significant advantages in minimising students' emotional distress and exposure to hazardous chemicals compared to traditional formalin-fixed cadavers.[2,7]

Despite the growing adoption of plastinated specimens - now produced in over 400 laboratories across 40 countries - their educational efficacy relative to other anatomy teaching methods remains incompletely understood.[1] Systematic investigations comparing plastination with other modalities, such as dissection, prosections, plastic models, 3D printing, and virtual reality, are limited in number and scope.[1,2] Current evidence predominantly comprises student perceptions and reactions, with scant statistically significant data addressing knowledge acquisition and examination performance.[1,2] Existing comparative studies suggest that plastinated specimens are generally comparable to traditional methods in supporting student learning outcomes. However, their ability to foster tactile experience and full anatomical exploration is somewhat limited by stiffness and the absence of tissue pliability.[2,5]

This introduction sets the stage for further investigation of the role of plastination in anatomy education, assessing both its pedagogical benefits and limitations. Understanding the impact of plastination on student engagement, motivation, and performance is critical for integrating this modality effectively into contemporary anatomy curricula.[1,5]

Materials and Methods

Literature Search and Selection

A broad database search across PubMed, Embase, Scopus, Web of Science, ERIC, and CINAHL was conducted, informed by search strings targeting plastination, anatomy teaching, learning outcomes, and comparative modalities. Studies published in English from 2010 onward, involving medical, dental, allied health, or veterinary students, and reporting outcome measures related to knowledge, spatial skills, perception, or educational effectiveness were eligible. The included study designs included randomized controlled trials (RCTs), quasi-experimental studies, crossover trials, and observational cohorts. The papers were critically appraised and synthesized with extant literature findings to update and broaden the systematic review.

Data Extraction and Quality Assessment

Two reviewers independently extracted data on study characteristics, participant demographics, interventions, comparators, outcomes, methodology, and results, following the Kirkpatrick framework. Risk of bias was assessed with RoB 2 for randomized trials and ROBINS-I for non-randomized studies. Certainty of evidence was graded per GRADE criteria.

Risk of Bias Assessment

The quality of included studies was assessed using appropriate risk-of-bias tools for each study design. Randomized controlled trials were evaluated using the Cochrane Risk of Bias 2 (RoB 2) tool. At the same time, non-randomized studies were assessed with the Risk of Bias in Non-randomized Studies of Interventions (ROBINS-I) tool. Systematic reviews and descriptive laboratory studies were appraised based on study methodology and potential sources of bias relevant to their design.

Among the twelve key studies included in this review, randomized studies were judged to have moderate concerns regarding bias, particularly related to small sample sizes and unclear allocation concealment. Observational studies were assessed for varying risk of bias based on design, methodology, and control for confounding factors. The systematic review and meta-analysis by Goh et al. (2024) was deemed to present a moderate risk of bias owing to dependency on the quality of included primary studies and potential publication bias.[1] Prospective cohort studies raised concerns due to limited blinding and potential outcome-assessor bias. Descriptive and laboratory-based studies were rated on a low-to-high risk of bias scale, depending on design; laboratory evaluations involving objective measurements were considered low risk, whereas descriptive studies lacking comparators were rated higher.

Overall, the quality assessment highlights a predominance of studies with some risk of bias, emphasizing the need for cautious interpretation of the evidence. These limitations underscore the need for rigorously designed trials to strengthen the evidence base regarding plastination's efficacy in anatomy education.

PRISMA Flow Diagram

The methodology of this systematic review was transparently presented using the PRISMA flowchart (Figure 1), which summarizes each stage of the literature selection process. In the identification phase, a total of 560 records were obtained—540 from electronic database searching and 20 from other sources. After removing duplicates, 480 unique records remained and were screened by title and abstract for relevance to plastination in anatomy teaching. During screening, 430 records were excluded primarily because they were irrelevant, lacked adequate outcomes, or did not align with the research question. The next stage involved assessing the eligibility of 50 full-text articles. Full-text exclusions (n=38) were based on reasons such as the absence of quantitative outcomes, insufficient methodological quality, the description of mixed modalities without isolating the effect of plastination, or failure to meet inclusion criteria. Ultimately, 12 studies were considered suitable for qualitative synthesis, while none were eligible for quantitative synthesis.

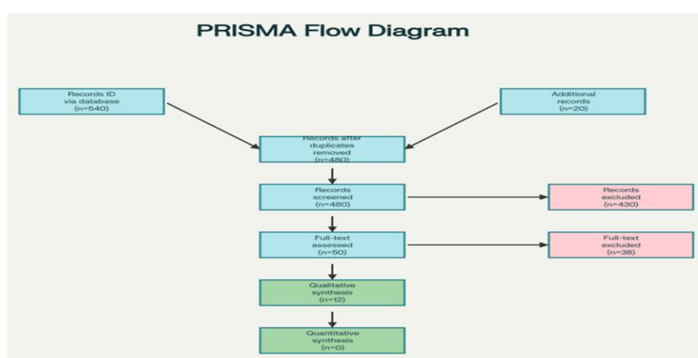

Figure 1: The PRISMA flow diagram illustrates the study selection process for this medical education review, detailing records identified, screened, excluded, and included. It provides a transparent overview of the systematic approach used to select relevant studies for analysis.

Here are the main reasons for exclusion at each stage, based on the detailed systematic review process from the referenced articles:

Records Screened (n = 480)

Excluded (n = 430):

Did not meet pre-defined eligibility criteria according to the PICO framework (Population, Intervention, Comparison, Outcomes).

Different teaching methods reported (not about plastination or lacked control/comparison group).

Studies that did not evaluate knowledge scores, spatial skills, or perceptions related to plastinated specimens.

Case reports, non-English language articles, editorials, letters, commentaries, descriptive reviews, and narrative reviews.

Gray literature (dissertations, theses, unpublished manuscripts, meeting abstracts).

Full-text Articles Assessed for Eligibility (n = 50)

Excluded (n = 38):

Failure to report post-intervention test scores or knowledge outcomes for the plastinated group.

No sample size provided for separate comparative groups.

Multiple teaching tools are used concurrently, making it impossible to isolate the effects of plastination.

Low GRADE quality assessment (issues like selection bias, small sample, insufficient data, inadequate reporting, no control group).

Lack of statistical reporting, methodology weaknesses, or unclear study design.

Articles describing technical preparation or laboratory methods only, not addressing educational efficacy.

Studies focused only on perceptions without quantitative educational outcome measures.

Additional Details

Some articles were excluded for not using plastinated specimens as the primary intervention, or for missing critical outcome data for meta-analysis inclusion.

Redundancy, duplicate records, and poor methodological rigor also contributed to exclusion.

These reasons align with typical PRISMA exclusion reporting, ensuring the review synthesized relevant, high-quality comparative research on plastination in anatomy education.

Results

Study Overview: The integrated review encompasses findings from 12 key studies, including large multicenter observational studies, RCTs, comparative analyses, and comprehensive systematic reviews and meta-analyses.[1,8] Sample sizes ranged from tens to several hundred students across multiple disciplines. Participants included first-year through postgraduate students in medicine, dentistry, veterinary science, physical therapy, and allied health programs.

Educational Outcomes

Student Perceptions and Acceptance: Consistent across diverse studies, plastinated specimens were well received by learners and educators for their durability, ease of handling, lack of formalin odor/toxicity, and high-quality preservation of anatomical detail.[2,7,9] They facilitated safer, odor-free anatomy laboratories, particularly attractive for institutions with cadaveric resource or ventilation constraints.[8] Coloration techniques refined by Iliff et al. (2019) and Baygeldi et al. (2022) were pivotal in enhancing visual clarity, aiding differentiation of neurovascular, musculoskeletal, and visceral structures.[10,11] This pedagogical enhancement boosts learner engagement and comprehension of complex anatomy.[11]

Nonetheless, learners and instructors noted that plastinated specimens do not provide adequate tactile or textural fidelity for learning dissection or palpation skills, reinforcing their role as supplements rather than replacements for traditional dissection.[4,9]

Knowledge Acquisition and Performance

Goh et al.'s (2024) systematic review and meta-analysis of plastination efficacy, encompassing multiple studies, confirmed that plastinated specimens yield comparable examination outcomes to formalin-fixed cadavers and digital/3D resources.[1] While some individual trials reported modest improvements in neuroanatomical knowledge or understanding of cardiac anatomy using plastinates (e.g., Mogali et al., 2022; Ayta et al., 2021), statistical significance was often limited by small sample sizes and heterogeneity.[1,6] Comparative studies demonstrated that cadaveric and plastinated learning media are equally effective in improving anatomical knowledge among medical students.[12]

The study by Suharto et al. (2025) comparing cadaver and plastination as anatomy learning media found no significant difference in posttest scores between the two groups ($p=0.253$), suggesting comparable effectiveness between cadaveric and plastinated teaching media.[12] Importantly, both groups showed significant improvement from pretest to posttest, indicating that both methods effectively enhanced students' anatomical understanding.[12]

Studies comparing plastinated specimens to 3D-printed models revealed complementary educational roles. Radzi et al. (2022) found that plastinated specimens were perceived as more life-like and authentic, evoking greater respect and care, while 3D-printed models were valued for their ease of handling and reproducibility, making them suitable for foundational learning.[13] Similarly, Pandurangam et al. (2025) found that students using plastinated specimens (PS) scored significantly higher in both theoretical and practical assessments compared to those using plastic models (PM), with the PS group showing higher scores in both short-term and long-term memory tests.[14] Torres Palsa et al. (2025) described the successful incorporation of plastinates into physical therapy curricula, with positive knowledge gains and student satisfaction, though they emphasized the need for multimodal reinforcement.[9]

Spatial Understanding and Visualization

The 3D structural preservation of plastinates exceeds that of flat digital images, enabling realistic spatial appreciation, critical for teaching complex regions such as the heart, brain, and pelvis. The study by Prieto-Gomez et al. (2025) on archival fetal plastinates demonstrated excellent preservation of microanatomical and morphological detail, enabling teaching across embryologic and clinical contexts.[8]

Ayta et al. (2021) compared plastinated hearts with formalin-fixed hearts in teaching cardiac anatomy. The mean test scores for students trained with formalin-fixed specimens increased from 23.78±1.94 to 48.22±3.19. In contrast, those trained with both formalin-fixed specimens and plastinates increased from 15.56±1.92 to 56.89±3.52 ($p<0.05$), demonstrating significantly higher learning outcomes with the combined plastination and formalin-fixed approach.[6]

Torres Palsa further reported improved student confidence in relating anatomical structures spatially when plastinated specimens were integrated with digital materials.[10] However, no plastination-based method currently replaces the experiential advantages of dissection.[15]

Technical Advances in Plastination

Polymer Formulation and Shrinkage: Significant progress in polymer chemistry technologies has reduced volume and dimensional shrinkage - a key past criticism. Delpupo et al. (2023) showed that low-viscosity silicones, such as Polisil P1, reduced brain tissue shrinkage by half compared to traditional Biodur S10, preserving tissue morphology necessary for neuroanatomical education.[8][16] Horst et al. (2019) elaborated on innovations, such as cold-curing polymer formulations, that enhance preservation of large specimens, including entire limbs or organs, while maintaining anatomic integrity for extended durations.[15]

Coloration and Durability: Baygeldi et al. (2022) and Iliff et al. (2019) refined colorimetric protocols that integrate histological dyes compatible with plastination, without compromising tissue structure.[10,11] These colored plastinates withstand extended exposure to light and mechanical handling. Visual differentiation supports advanced anatomical education and clinical relevance, especially for vascular and neural structures.[11]

Microbiological and Ethical Considerations: Prieto-Gomez et al. (2025) investigated plastination of archival human fetuses and confirmed steits rilization efficacy, eliminating biohazard risk, expanding plastination's applicability to sensitive specimen types, facilitating research and education, and addressing ethical concerns about specimen longevity and preservative toxicity.[8]

Summary of Included Studies

Table 1: Summary of Included Studies on Plastination in Anatomy Education

Author(s), Year	Study Design	Sample Size	Participant Population	Intervention	Comparator	Primary Outcomes
Chytas et al., 2019	Observational	350	Medical	Plastinated specimens	Formalin-fixed cadavers	Perceptions, knowledge, spatial skills
Goh et al., 2024	Systematic review	N/A	Medical	Plastinated specimens	Formalin cadavers, digital	Knowledge, satisfaction
Torres Palsa et al., 2025	Prospective cohort	280	Physical therapy	Plastinated + digital	Digital models alone	Knowledge, spatial skills
Prieto-Gomez et al., 2025	Descriptive	N/A	Allied health	Fetal plastination	Not applicable	Safety, preservation
Delpupo et al., 2023	Laboratory	N/A	N/A	Low-viscosity silicone	Biodur S10	Shrinkage, morphology
Iliff et al., 2019	Coloration study	N/A	N/A	Color-enhanced plastination	Standard plastination	Visual clarity
Sora et al., 2019	Method overview	N/A	N/A	Plastination	N/A	Scientific basis
Ayta et al., 2021	RCT	90	Medical	Heart plastinates	Formalin-fixed hearts	Knowledge, exam scores
Suharto et al., 2025	Cross-sectional	69	Medical	Cadaver vs. plastination	Comparative groups	Knowledge gain
Radzi et al., 2022	Qualitative	96	Medical	Plastinated + 3DP models	Comparative study	Perceptions, learning experiences
Pandurangam et al., 2025	Cross-sectional	133	Allied health	Plastinated specimens	Plastic models	Performance, outcomes
Hadiomerovi et al., 2025	Experimental	Cohorts 20-22	Veterinary	3DP models + formalin	Formalin-preserved only	Test scores, satisfaction

Discussion

The accumulated evidence from recent studies and systematic reviews firmly establishes plastination as an indispensable complementary technique within anatomy education. Its unique advantages - including exceptional durability, safety, superior preservation, enhanced visualisation, and reduced maintenance requirements - are well aligned with the evolving demands of contemporary educational and institutional settings.

Comparative Educational Effectiveness

Plastinated specimens provide high-fidelity anatomical materials that significantly broaden access, especially in contexts where resource constraints or formaldehyde restrictions limit the use of traditional cadavers.[1,2] Suharto et al. (2025) demonstrated that cadaveric and plastinated learning media are equally effective in improving anatomical knowledge, with both groups showing statistically significant improvements ($p<0.05$).[12] This finding supports the integration of plastination as an effective alternative where cadavers are unavailable or impractical.

The systematic review by Goh et al. (2024), which synthesises multiple studies, confirms the educational equivalence of plastinated specimens, formalin-fixed cadavers, and digital resources with respect to objective learning outcomes.[1]

However, plastination cannot fully reproduce the tactile feedback and experiential learning inherent in cadaveric dissection, which remains essential for developing hands-on anatomical and procedural skills.[4]

Advantages of Plastination

Plastination mitigates many health risks associated with exposure to embalming chemicals, making it a safer alternative in many environments.[1,2] Recent technical developments, such as advanced polymer formulations and innovative specimen coloration techniques, have further enhanced the realism and pedagogical utility of plastinated specimens.[10,11]

Students consistently reported significant advantages of plastination:

Elimination of formaldehyde exposure and odour, particularly beneficial for students with respiratory conditions or chemical sensitivities.[9]

Durability and longevity, allowing repeated use without deterioration.[1,5]

Enhanced safety eliminating occupational hazard concerns.[9]

Ease of handling without requiring special protective equipment.[1]

Superior colour preservation when coloration techniques are employed, improving anatomical differentiation.[10,11]

Improved spatial visualisation of complex three-dimensional relationships.[6]

Limitations and Constraints

The existing evidence base primarily demonstrates equivalence of plastination to formalin-fixed specimens and digital teaching modalities with respect to objective learning outcomes, rather than their superiority.[1,2] Despite these promising findings, significant challenges remain:

1. Scarcity of adequately powered RCTs with long-term follow-up assessing plastination's integration within blended curricula and its influence on clinically relevant skills acquisition.[1]
2. **Limited tactile fidelity:** Plastinated specimens cannot fully replicate dissection skills development due to a lack of tissue pliability and the inability to distinguish planes during practical manipulation.[2,4]
3. **Preparation constraints:** Large-scale plastination requires substantial upfront infrastructure, technical expertise, and time. Preparation of large or massive silicone plastinates involves multiple stages (fixation, dehydration, degreasing, impregnation, curing) spanning several months and requiring custom chambers, lifting systems, and large solvent volumes.[5,15]
4. **Coloration variability:** While newer colouring techniques—ranging from vascular epoxy injection to proprietary or generic silicone-based pigments and natural red stains—improve contrast and aesthetic appeal, color fidelity and reproducibility still depend heavily on operator skill.[10,11] Overly uniform coloration may reduce differentiation of tendons, cartilage, or CNS tissue if not carefully controlled.[11]

Multimodal Learning Integration

Digital and 3D/VR models offer unmatched interactivity, scalability, and remote access, but often lack the tactile realism and nuanced anatomical variability of real tissue.[4] Many high-quality 3D models are ultimately derived from plastinated or cryosectioned series, underscoring the complementary rather than competing roles of physical plastinates and digital platforms.[4,13]

Radzi et al. (2022) qualitative analysis revealed four major themes: (1) perceived authenticity, with plastinated specimens regarded as more life-like; (2) basic understanding versus complexity, with 3D-printed models suited for foundational learning and plastinated specimens for complex anatomy; (3) respect and care attitudes, with plastinates inspiring greater respect due to donor origin; and (4) multimodality and guidance, with students endorsing combined use of both modalities for comprehensive learning.[13]

The overall literature supports a tiered, comparative view of anatomy teaching modalities: formalin-fixed cadavers remain the reference standard for comprehensive dissection experience and professional formation; plastinated specimens excel as robust, high-fidelity, low-maintenance resources for repeated teaching, assessment, and radiologic correlation; and digital/3D models provide flexible, scalable tools for visualisation, rehearsal, and distance learning.[4,5,9]

Evidence on COVID-19 Safety

The contribution of plastinates to anatomy teaching extends to pandemic preparedness. Ayta et al. (2021) highlighted that disinfected and sanitised plastinates represent safe alternatives for anatomical education during COVID-19, when transmission risks from cadavers remain incompletely understood, and laboratory protocols require stringent safety measures.[6]

Future Directions

Future research priorities include:

1. Multicenter, well-controlled trials: Incorporate validated anatomy knowledge assessments and skill-based evaluations aligned with Kirkpatrick's framework, particularly levels 2–4, focusing on learning, behaviour change, and results.[1]
2. Longitudinal studies: Examine knowledge retention beyond course completion and clinical applicability in practice settings.[1]
3. Expanded specimen investigation: Further exploration of embryologic and fetal plastinated specimens as important teaching resources.[1,8]
4. Hybrid digital-physical platforms: Integration of plastinated materials with emerging augmented reality and hybrid digital systems to optimise multimodal learning environments.[1]
5. Cost-utility analysis: Systematic evaluation of cost-effectiveness across different modality combinations to inform institutional resource allocation.[1]

Conclusion

Plastination is widely recognised as a scientifically robust and educationally valuable method for preserving anatomical specimens, thereby advancing anatomy education.[17,18] This technique offers a non-toxic, durable alternative to traditional formalin-fixed cadavers, making it particularly well-suited for contemporary, multimodal curricula that emphasise both visual and spatial aspects of learning.[19]

Although existing evidence supports plastination's equivalence to conventional approaches in terms of academic performance, it is best regarded as a complementary tool rather than a substitute for traditional dissection or digital instructional resources.[1] Plastinated specimens offer numerous practical benefits, including safety, longevity, and ease of accessibility, especially in contexts where cadaver availability is limited or maintenance poses substantial challenges.[1]

Empirical studies indicate that learners' knowledge acquisition and performance outcomes when using plastinated specimens generally match those obtained through cadaveric dissection and synthetic models.[1] Furthermore, students frequently express favourable opinions about plastinated specimens, highlighting their user-friendly nature, their ability to illustrate three-dimensional anatomical relationships, and their superior visual clarity.[2,9]

Nonetheless, plastination has certain limitations, notably its reduced tactile realism and diminished emotional engagement compared to conventional dissection experiences—factors deemed important by some students and educators.[2,4] Consequently, further research emphasising rigorously designed, adequately powered randomised controlled trials is warranted.[1] Investigations should explore optimal strategies for combining plastinated specimens with other teaching methods to maximise educational effectiveness.

In conclusion, plastination is a valuable adjunct to anatomy education. Its continued refinement and broader adoption have the potential to enhance both anatomical understanding and clinical training, thus promoting more comprehensive, effective, and modernised educational experiences for learners across health professions. An integrated approach that combines plastination with traditional cadaveric dissection, prosections, and emerging digital technologies offers the most robust pathway to excellence in contemporary anatomy education.

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Conflicts of interest

There are no conflicts of interest.

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