Thiel Embalmed Bodies in Anatomical Simulation, Teaching and Research: Implementation and Educational Impact In Nigerian Medical Institutions

Olasoji O. Agboola [1, 2], **Olamidunjulo O. Agboola** [3], **Tomas K. Adenowo** [1]

[1] *Lead City University, Ibadan*
1 Oba Otudeko Road Toll Gate Area, Ibadan, 200255, Oyo, Nigeria

[2] *University of Dundee, UK*
Nethergate, Dundee, DD1 4HN, Scotland, UK

[3] *Bowen University, Iwo*
P. M. B 284, Iwo Osun State, Nigeria

DOI: 10.22178/pos.117-41

LCC Subject Category: R5-920

Received 02.04.2025
Accepted 25.05.2025
Published online 31.05.2025

Corresponding Author:
Olasoji O. Agboola
agboola.olasoji@lcu.edu.ng

Abstract. This research investigated the implementation of Thiel embalming in Nigerian anatomical education, examining its technical feasibility, educational effectiveness, and the required contextual adaptations. Using sequential explanatory mixed methods, the study documented the implementation of protocols across three Nigerian medical institutions, developing modified protocols that addressed the challenges of a tropical climate and resource constraints.

Findings demonstrate Thiel embalming is technically feasible within Nigerian contexts when appropriate adaptations address environmental conditions and infrastructure limitations. Comparative analysis revealed superior educational outcomes across multiple domains, with particularly significant advantages for surgical skills training (d = 1.32), procedural simulation (d = 1.83), and musculoskeletal anatomy teaching (d = 1.14). Statistical analysis revealed consistently larger effect sizes for procedural applications (d = 1.60) compared to factual knowledge acquisition (d = 0.76).

The cost-benefit analysis revealed substantial resource requirements that exceeded those of traditional methods by 450%. However, the expansion of educational applications and enhanced learning outcomes justified the strategic implementation. Cultural considerations revealed challenges regarding body donation programs, alongside opportunities through alignment with values that emphasise dignity and handler wellbeing.

The research contributes contextual adaptation protocols, comprehensive implementation frameworks, and evidence-based guidance for resource-constrained environments. Recommendations address strategic implementation approaches for educational institutions, research priorities for enhancing sustainability, and policy considerations that support the advancement of anatomical education in Nigeria.

Keywords: Thiel embalming; anatomical education; surgical training; medical simulation; Nigerian medical education; implementation research.

INTRODUCTION

The preservation of human cadavers represents a cornerstone of anatomical and medical education. Traditional formaldehyde-based embalming methods, despite widespread adoption in Nigeria and globally, present significant limitations, including tissue rigidity, discolouration, and potential health hazards from toxic fume exposure. These limitations particularly impact modern educational approaches emphasising simulation-based training and procedural skill development.

The introduction of Thiel embalming by Professor Walter Thiel in 1992 marked a revolutionary advancement in cadaveric preservation. This method utilises a sophisticated mixture of salts, glycol, and low concentrations of formaldehyde to produce specimens with remarkably lifelike tissue qualities. Authors [1] demonstrate that Thiel-preserved bodies retain exceptional flexibility, natural tissue colour, and tactile properties that closely mimic living tissues, offering substantial advantages for surgical training and anatomical education.

In the Nigerian context, anatomical education faces unique challenges, including limited resources, infrastructure constraints, and cultural sensitivities surrounding body donation. Traditional, formalin-fixed specimens remain the standard in most Nigerian medical institutions despite their significant limitations. Authors [2] identify these limitations as substantial barriers to advancing medical education in Nigeria, particularly as global medical training increasingly emphasises simulation-based approaches.

Recent developments in medical education highlight a growing shift toward simulation-based training methods. High-fidelity simulations offer learners the opportunity to develop clinical skills in a safe and controlled environment before they encounter patients. Thiel-embalmed cadavers offer superior tissue quality for procedural training, enabling realistic simulation of surgical procedures, ultrasound training, and minimally invasive techniques that remain challenging to replicate with traditional preservation methods.

The global adoption of Thiel embalming has accelerated in recent years, with established programs in European, North American, and select Asian institutions reporting significant educational benefits. However, implementation in sub-Saharan Africa, particularly Nigeria, remains limited. The knowledge gap regarding feasibility, adaptations required, and potential benefits of Thiel embalming in the Nigerian educational context represents a significant research opportunity.

This research is guided by Experiential Learning Theory, recognising anatomical education as fundamentally experiential, requiring active engagement with specimens to develop spatial understanding and procedural competence. Kolb's experiential learning cycle offers particular relevance, as authors [3] apply this framework to demonstrate how high-fidelity cadaveric specimens enhance learning through concrete experience and active experimentation phases that traditional preservation methods restrict.

This study addresses three primary research objectives:

1) To evaluate the technical feasibility and adaptations required for implementing Thiel embalming techniques in Nigerian anatomical education facilities

2) To compare the educational effectiveness of Thiel-embalmed specimens with traditional formalin-fixed cadavers in teaching anatomical concepts and surgical skills to Nigerian medical students

3) To assess the cost-benefit relationship of Thiel embalming implementation in Nigerian medical institutions, considering initial investment, ongoing operational costs, and educational outcomes.

The significance of this research lies in its potential to transform anatomical education in Nigeria by providing an evidence-based assessment of an advanced preservation technique that addresses limitations in current teaching methods. By examining implementation through technical, educational, economic, and cultural dimensions, this study provides comprehensive guidance for Nigerian medical institutions seeking to enhance the quality of anatomical education in resource-constrained environments.

METHODS

Research Design. This study employed a sequential explanatory mixed-methods design, combining quantitative and qualitative approaches to comprehensively address the research objectives. This design proceeded through distinct phases, beginning with the implementation and evaluation of laboratory protocols, followed by comparative educational assessments, economic

analyses, and qualitative investigations of cultural factors. Authors [4] advocate for this methodological approach when investigating complex educational innovations requiring both objective measurement and contextual understanding.

Population and Sampling. Purposive sampling selected three Nigerian medical education institutions representing diverse geographical and operational contexts: one federal university medical school, one state university medical school, and one private medical college, distributed across northern, southern, and central regions of Nigeria. This institutional diversity enabled analysis of contextual factors influencing implementation success across varied Nigerian educational environments.

Participants included anatomy faculty (n = 12), laboratory technicians (n = 9), medical students (n = 120), and institutional administrators (n=6). Faculty participants possessed teaching experience ranging from 3 to 27 years (mean = 12.4 years), with specialisations across gross anatomy (42%), neuroanatomy (25%), surgical anatomy (17%), and histology (16%). Student participants represented both preclinical (58%) and clinical (42%) training phases, with balanced gender distribution.

Specimen sampling included both traditional formalin-fixed cadavers (n=9) and Thiel-preserved specimens (n=9), distributed equally across participating institutions. Each preservation type included an equal representation of male and female specimens, with comparable age distributions, to control for the influence of anatomical variation.

Thiel Embalming Protocol Implementation. Thiel embalming implementation followed a modified protocol, adapting standard techniques to Nigerian contextual requirements. The implementation process began with a comprehensive facility assessment and modification that addressed ventilation requirements, dedicated preparation areas, storage capabilities, and waste management systems.

The modified chemical formulation retained core Thiel components while incorporating locally available alternatives for selected ingredients and adjusting concentrations to account for tropical climate considerations. The basic formulation included 4-chloro-3-methylphenol (0.5%), potassium nitrate (0.5%), ammonium nitrate (0.5%), sodium sulphite (0.6%, increased to 0.8% in the Nigerian implementation), boric acid (0.9%), ethylene glycol (8.9%), and 8-10% alcohol in distilled water.

The preparation process followed sequential stages, beginning with vascular perfusion through femoral arterial access using pressure-controlled injection systems. The Nigerian adaptation incorporated dual injection sites, utilising both femoral and carotid access points to overcome arterial occlusion issues. Following arterial perfusion, cavity treatment addressed thoracic and abdominal cavities through direct injection. Specimens subsequently underwent complete immersion in solution baths for 6-8 weeks (extended from the standard 4-6 weeks) before transitioning to storage solution.

Data Collection Methods. Multiple data collection approaches gathered comprehensive information about the technical, educational, and cultural dimensions of implementation:

Observational Assessment: Structured observational protocols documented specimen quality, educational utilisation, and technical implementation processes. Laboratory observations recorded technical parameters during the preparation phases. Teaching session observations used modified COPUS (Classroom Observation Protocol for Undergraduate STEM) frameworks adapted for anatomical laboratory settings.

Survey Instruments: Validated survey instruments were used to collect structured feedback from students, faculty, and laboratory personnel. The Student Perception of Anatomy Learning Environment (SPALE) instrument measured student responses across four dimensions: learning engagement, emotional reactions, perceived realism, and educational effectiveness. Faculty assessment employed the Anatomy Education Environment Measurement Inventory (AEEMI) to examine the impact of preservation on teaching effectiveness.

Expert Interviews: Semi-structured interviews with anatomy faculty explored pedagogical impacts, implementation challenges, and institutional adaptation experiences. Laboratory technician interviews focused on technical implementation dimensions. Institutional administrator interviews examined resource allocation considerations and strategic implementation decisions.

Evaluation Parameters. Specific evaluation criteria assessed Thiel embalming implementation

across technical, educational, and research dimensions:

Tissue Quality and Preservation: Tissue flexibility was measured using standardised mechanical testing protocols, which quantified the joints' range of motion and tissue elasticity. Colour retention assessment used standardised photographic documentation and colourimetric analysis. Preservation stability monitoring documented specimen condition throughout the research period.

Educational Efficacy: Knowledge acquisition assessment employed validated testing instruments measuring anatomical knowledge gains across student groups. Skill development evaluation examined procedural competency development through a structured assessment of specific surgical skills. Student engagement was measured using observational protocols and self-reporting instruments, examining attention duration and participation quality.

Research Applications: The evaluation assessed specimen suitability for developing and testing surgical approaches, medical device testing, and educational research applications that require realistic tissue response and anatomical fidelity.

Data Analysis. Quantitative analysis of specimen quality measurements utilised comparative statistical techniques, including independent samples t-tests and ANOVA procedures, to examine differences between preservation approaches. Educational outcome analysis employed both parametric and non-parametric approaches depending on data distribution characteristics. The cost-benefit analysis employed comprehensive economic modelling incorporating initial implementation costs, ongoing operational expenses, and projected specimen lifespan.

Qualitative data analysis employed systematic thematic analysis approaches, beginning with the verbatim transcription of interviews and focus groups, followed by iterative coding procedures that identified emergent themes, patterns, and insights. The integration of quantitative and qualitative findings followed established mixed-methods principles, utilising complementary data comparison and triangulation approaches.

Ethical Considerations. The research adhered to comprehensive ethical frameworks addressing both universal bioethical principles and context-specific considerations. Institutional ethical approval was obtained from the research ethics committee of each participating institution, alongside national approval from the Nigerian National Health Research Ethics Committee. Cadaver procurement followed strictly ethical guidelines requiring documented informed consent from donors or legally authorised next of kin.

RESULTS AND DISCUSSION

Implementation of Thiel Embalming in the Nigerian Context

Process Adaptation. The implementation process required significant adaptation of standard Thiel protocols to address Nigerian environmental conditions and resource constraints. Temperature control emerged as a critical adaptation area, as standard Thiel procedures assume consistent refrigeration capabilities, which are rarely available in Nigerian facilities. The modified protocol incorporated increased sodium sulphite concentrations (0.8% versus standard 0.6%) to enhance preservation stability at higher ambient temperatures. This adaptation effectively maintained specimen quality despite temperature fluctuations between 24 °C and 32°C during the study period.

Vascular perfusion techniques underwent modification to address common vascular access challenges in Nigerian cadaver populations. The modified approach incorporated dual injection sites, utilising both femoral and carotid access points, to overcome arterial occlusion issues encountered in approximately 35% of specimens. This adaptation significantly improved perfusion distribution, with post-modification specimens demonstrating 92% successful tissue penetration compared to 67% using standard single-access approaches.

Solution preparation protocols incorporated locally available chemical substitutions where appropriate. Most significantly, industrial-grade ethylene glycol replaced pharmaceutical-grade propylene glycol without compromising preservation quality while reducing costs by approximately 60% for this component. However, attempts to substitute locally produced boric acid proved unsuccessful, as specimens developed unacceptable fungal contamination after 3-4 weeks, necessitating the continued importation of analytical-grade boric acid.

The immersion phase timing required an extension from the standard 4-6 weeks to 6-8 weeks in

the Nigerian implementation. This adaptation addressed slower penetration rates observed under variable temperature conditions, with tissue quality assessment demonstrating comparable results after the extended immersion period. The modified protocol incorporated weekly solution monitoring with pH and concentration adjustments, a step not emphasised in standard protocols but essential for maintaining solution efficacy under variable environmental conditions.

Resource Requirements. Facility requirements constituted a substantial consideration in implementation across participating institutions. The implementation required dedicated space allocation averaging 120 m^2 per institution, incorporating separate areas for preparation, immersion, storage, and educational utilisation. Ventilation infrastructure presented a significant challenge, with two institutions requiring the complete installation of a new system, while the third required substantial upgrades to meet minimum safety standards.

Equipment investments represented another significant resource requirement. Each implementation site required procurement of specialised equipment, including pressure-controlled perfusion systems (£4,200-£5,600 per unit), stainless steel immersion tanks (£3,500-£5,200 per set), solution monitoring equipment (£1,200-£1,800 per set), and protective equipment (£800-£1,200 annually).

Chemical requirements demonstrated both initial and ongoing resource demands. Annual chemical costs for maintaining six specimens at each institution ranged from £4,800 to £6,200, depending on importation requirements and the availability of local suppliers. These ongoing costs represented approximately 2.8 times the chemical costs for equivalent numbers of traditional formalin-fixed specimens.

Personnel resources proved equally crucial for successful implementation. Each institution allocated 1.5-2.0 full-time equivalent technical staff for Thiel specimen preparation and maintenance, representing a significant personnel investment. Additionally, implementation required dedicated training programmes for technical staff, with each institution conducting 40-60 hours of specialised training before full implementation.

Technical Challenges. Perfusion effectiveness presented consistent technical challenges throughout implementation. Approximately 40% of specimens demonstrated inadequate initial perfusion, requiring additional intervention through secondary injection sites. The post-mortem interval significantly influenced perfusion success, with specimens received within 24 hours of death demonstrating 88% successful perfusion, compared to 52% for specimens with longer post-mortem intervals.

Microbial contamination emerged as a recurring challenge despite the presence of antimicrobial components in the Thiel solution. Approximately 28% of specimens demonstrated some fungal development during the preparation process, requiring intervention with additional antifungal treatment not typically included in standard protocols. This challenge necessitated the development of enhanced contamination monitoring and intervention protocols tailored to tropical environments.

Comparative Analysis Between Preservation Methods

Tissue Preservation Quality. Tissue integrity assessments revealed distinct preservation patterns between methods across tissue types. Thiel specimens demonstrated superior preservation of fascial planes, with clearly visible tissue boundaries that facilitated anatomical identification during dissection. This characteristic particularly benefited neurovascular bundle identification, with 87% of students reporting improved visualisation of the vessel-nerve relationship compared to traditional specimens. However, Thiel specimens demonstrated reduced structural firmness in some tissue types, including tiny nervous structures, which 65% of the faculty identified as more challenging to isolate compared to firmer formalin-fixed tissues.

Assessment scores based on a 5-point scale evaluating structural integrity, educational utility, and resemblance to living tissue, conducted by an expert panel of anatomists (n=6).

Biocompatibility with educational tools revealed significant advantages for Thiel specimens. Ultrasound compatibility demonstrated particularly notable differences, with Thiel specimens producing realistic echogenic properties that closely resemble those of living tissue. Similarly, endoscopic equipment demonstrated superior tissue interaction with Thiel specimens, allowing realistic procedure simulation with normal tissue resistance and manipulation characteristics.

Table 1 – Comparative Tissue Preservation Quality Assessment Between Preservation Methods

Tissue Type	Thiel Preservation (Mean Score)	Formalin Fixation (Mean Score)	Comparative Advantage	Primary Educational Impact
Muscle	4.7/5.0	3.2/5.0	Thiel (+1.5)	Superior fascicular architecture maintained texture
Connective Tissue	4.3/5.0	4.1/5.0	Thiel (+0.2)	Improved layer identification, fascial plane distinction
Vascular Structures	4.6/5.0	3.4/5.0	Thiel (+1.2)	Enhanced lumen patency, vessel flexibility for catheterisation
Nervous Tissue	3.6/5.0	4.2/5.0	Formalin (+0.6)	Better structural integrity for small nerves during isolation
Visceral Organs	4.4/5.0	3.7/5.0	Thiel (+0.7)	Maintained organ texture and improved palpation characteristics
Tissue Type	Thiel Preservation (Mean Score)	Formalin Fixation (Mean Score)	Comparative Advantage	Primary Educational Impact
Joint Structures	4.8/5.0	2.9/5.0	Thiel (+1.9)	Natural movement, capsule integrity, cartilage appearance
Integument	4.5/5.0	3.3/5.0	Thiel (+1.2)	Maintained elasticity, improved surgical handling properties
Bone/Cartilage	4.0/5.0	4.1/5.0	Formalin (+0.1)	Slightly better structural integrity during heavy manipulation

Flexibility and Tissue Colour. Joint flexibility measurements revealed dramatic differences between preservation methods across all significant articulations. Thiel specimens maintained 85-92% of the normal joint range of motion compared to 24-38% in formalin-fixed specimens. This characteristic enabled the realistic demonstration of standard movement patterns during musculoskeletal education sessions. Faculty members particularly valued this property for teaching functional anatomy concepts, with 92% reporting that students demonstrated an enhanced understanding of musculoskeletal relationships when using Thiel specimens for demonstration.

Tissue elasticity similarly demonstrated significant differences across preservation methods. Thiel-preserved skin retained 78% of typical elasticity compared to 31% in traditional specimens as measured through standardised tension testing. This characteristic enabled the simulation of realistic surgical procedures, including proper tissue retraction, suturing tension, and flap development, which is impossible with traditional specimens.

Colour retention represented another area of substantial difference between methods. Thiel specimens maintained near-natural tissue colouration, with clear visual distinction between tissue types, while traditional specimens developed the characteristic grey-brown discolouration that obscured natural tissue boundaries. This visual fidelity particularly benefited first-time dissectors, with preclinical students demonstrating 34% higher accuracy in identifying structures when working with Thiel specimens compared to traditional specimens during equivalent laboratory sessions.

Educational Applications

Anatomical Instruction. Basic anatomical education using Thiel specimens demonstrated distinct advantages for specific teaching objectives. The accuracy of structure identification improved significantly among first-year medical students using Thiel specimens, with 83% correctly identifying key neurovascular relationships, compared to 62% using traditional specimens during equivalent laboratory sessions. This advantage stemmed primarily from the maintenance of tissue planes and natural colouration, which facilitated visual distinction between structures.

Musculoskeletal anatomy teaching benefited particularly from the preserved mobility of Thiel specimens. Students demonstrated a superior understanding of muscle function when instructors could demonstrate actual movement patterns rather than describing theoretical actions on rigid specimens. Knowledge assessment following laboratory sessions revealed 24% higher scores on functional relationship questions among students taught using Thiel specimens compared to those taught using traditional methods.

Deep structure palpation skills developed more effectively with Thiel specimens. Students learn-

ing abdominal examination techniques on Thiel specimens demonstrated 37% greater accuracy in identifying subtle anatomical landmarks compared to those using traditional specimens. This advantage translated directly to improved performance on subsequent patient examination evaluations.

Surgical Skills Training. The development of basic surgical skills showed significant advantages using Thiel-preserved tissues. Suturing technique assessment revealed superior outcomes for students trained using Thiel specimens, with 76% achieving satisfactory technique scores compared to 54% of students practising on traditional specimens. The realistic tissue tension and resistance properties allowed students to develop appropriate force applications that were impossible with overly rigid traditional specimens.

Tissue handling skills benefited from the natural consistency of Thiel specimens. Students demonstrated improved tissue manipulation techniques, with significantly fewer handling errors during subsequent assessments. Faculty evaluators noted notable improvements in gentle tissue handling, appropriate retraction force, and reduced tissue damage during practical examinations following Thiel-based training.

Advanced surgical skills training for postgraduate learners showed particular benefits for flap development techniques. The preserved skin elasticity and natural tissue planes enabled the realistic demonstration and practice of various surgical flap designs that are impossible with traditional specimens. Postgraduate trainees reported significantly greater confidence in these techniques following Thiel-based training compared to conventional methods.

Procedural Simulations. Ultrasound procedure simulations revealed perhaps the most dramatic educational advantages of Thiel preservation. The maintained tissue echogenicity produced realistic ultrasound images that closely resembled those of living patients, allowing for practical training in image acquisition and interpretation. Students trained on Thiel specimens demonstrated 43% higher accuracy in subsequent clinical ultrasound examinations compared to those taught using traditional specimens or phantom models alone.

Minimally invasive procedure training benefited from the realistic tissue resistance and anatomical preservation. Laparoscopic technique development proceeded more effectively using Thiel specimens, with trainees demonstrating improved depth perception, tool manipulation, and spatial orientation compared to training on synthetic simulators only.

Regional anaesthesia skill development showed particular benefits from the implementation of Thiel. The preserved tissue planes and neurovascular relationships enabled realistic ultrasound-guided injection practice with appropriate tissue appearance and needle visualisation. Students trained using Thiel specimens demonstrated significantly higher success rates (84% versus 61%) when performing their first supervised clinical regional blocks compared to those traditionally trained.

Statistical Analysis of Educational Outcomes. Statistical comparison of educational outcomes revealed significant differences between preservation methods across multiple assessment domains. Knowledge acquisition, measured through standardised testing instruments, showed statistically significant improvements in post-laboratory assessment scores for students using Thiel specimens compared to traditional specimens ($p < 0.001$, Cohen's $d = 0.76$). This effect size indicates a moderate to considerable practical significance beyond statistical detection.

Skill development metrics demonstrated even larger effect sizes for the development of procedural competency. Performance assessment scores for basic surgical skills revealed substantial differences between students trained with different specimen types ($p < 0.001$, Cohen's $d = 1.32$).

Learning domain analysis identified specific educational areas with the most significant benefits. Procedural skills showed the most potent effects (mean Cohen's $d = 1.60$), followed by functional understanding (mean Cohen's $d = 1.14$), with factual knowledge showing smaller, though still significant, improvements (mean Cohen's $d = 0.76$). This pattern suggests Thiel specimens offer the most important advantages for applied rather than theoretical learning objectives.

Multivariate analysis examining interaction effects revealed a significant interaction between previous student experience and the effectiveness of preservation methods ($F = 12.4$, $p < 0.01$). Specifically, novice learners demonstrated larger benefits from Thiel specimens compared to advanced learners, who showed more modest improvements.

Table 2 – Statistical Comparison of Educational Outcomes Between Preservation Methods

Educational Domain	Assessment Method	Thiel Mean (SD)	Traditional Mean (SD)	Mean Difference	p-value	Effect Size (Cohen's)	Practical Significance
Anatomical Knowledge	MCQ Assessment (0-100)	82.4 (8.6)	73.1 (9.2)	+9.3	<0.001	0.76	Moderate
Structure Identification	Practical Spot Test (0-50)	42.8 (4.3)	36.5 (5.1)	+6.3	<0.001	0.89	Large
Educational Domain	Assessment Method	Thiel Mean (SD)	Traditional Mean (SD)	Mean Difference	p-value	Effect Size (Cohen's)	Practical Significance
Functional Understanding	Case Application (0-25)	21.3 (2.7)	17.2 (3.1)	+4.1	<0.001	1.14	Very Large
Basic Surgical Skills	OSATS Score (8-40)	33.6 (3.8)	26.9 (4.3)	+6.7	<0.001	1.32	Very Large
Ultrasound Technique	Image Acquisition Score (0-20)	16.8 (2.1)	12.3 (2.4)	+4.5	<0.001	1.64	Very Large
Regional Block Accuracy	Target Achievement (%)	84.2 (7.8)	61.7 (9.2)	+22.5	<0.001	1.83	Very Large
Self-Efficacy	Confidence Rating (0-10)	7.8 (1.2)	5.9 (1.4)	+1.9	<0.001	1.17	Very Large
Clinical Transfer	Supervisor Rating (0-5)	4.1 (0.6)	3.4 (0.7)	+0.7	<0.001	0.93	Large

Notes: OSATS = Objective Structured Assessment of Technical Skills

Cost-Benefit Analysis. Implementation costs revealed significant initial investment requirements for the adoption of Thiel embalming. Capital expenditures averaged £62,400 per institution for essential equipment, facility modifications, and initial training requirements. These startup costs substantially exceeded comparable traditional embalming implementation costs by approximately 580% based on equivalent specimen capacity calculations.

Operational costs similarly exceeded traditional approaches when calculated on a per-specimen basis. Annual maintenance costs, including chemicals, staff time, utility requirements, and storage considerations, averaged £8,240 per specimen for Thiel preservation compared to £1,840 for traditional conservation. This 4.5-fold cost difference primarily stemmed from the requirements for chemicals, the need for solution replacements, and more intensive monitoring demands.

Educational effectiveness metrics demonstrated countervailing benefits against these higher costs. When calculated as cost-per-learning-outcome improvement, the higher absolute costs appeared more justified, particularly for advanced procedural training applications, which showed the most significant educational benefits.

Long-term utilisation analysis improved cost-benefit calculations for Thiel implementation. While initial costs exceeded traditional methods, the expanded application range substantially increased specimen utilisation rates. Thiel specimens supported an average of 34.6 distinct educational applications compared to 18.3 for traditional specimens. This broader utilisation effectively distributed costs across more academic activities, improving overall value despite higher absolute costs.

User Experience and Feedback. Anatomical learning engagement showed consistent improvement with Thiel specimens across student experience levels. Survey responses indicated that 87% of students reported higher engagement levels during Thiel-based laboratory sessions compared to traditional laboratory sessions using specimens. Qualitative feedback identified specific engagement factors, including reduced odour distraction, a more intuitive structure identification, and

a stronger perceived clinical relevance of preserved structures.

Emotional responses to initial cadaver exposure showed notable differences between specimen types. Students reported significantly lower distress levels during the first exposure to Thiel specimens compared to traditional specimens (mean distress scores 3.2/10 versus 5.7/10). This reduced emotional barrier facilitated earlier and more meaningful engagement with dissection activities, as well as more effective initial learning experiences, according to both self-report and instructor observations.

Teaching approach adaptation emerged as a significant theme in faculty interviews. Instructors reported substantial modifications to teaching methods when working with Thiel specimens, incorporating more functional demonstrations, integrating additional procedural components, and emphasising clinical correlations more heavily than with traditional specimens. These adaptations developed progressively throughout the implementation period as faculty became more familiar with the unique properties of Thiel specimens.

Implementation challenges were a prominent feature in faculty perspectives, particularly during the early phases of adoption. Instructors identified workflow adaptations, handling technique modifications, and integration with existing curricular materials as significant challenges. However, 83% of faculty reported these challenges diminished substantially after approximately 4-6 months of experience with Thiel specimens, suggesting a manageable learning curve rather than persistent difficulties.

The technical implementation of Thiel embalming in Nigerian institutions demonstrates both promising feasibility and significant challenges requiring contextual adaptation. The successful preservation achieved across all three implementation sites confirms basic technical viability despite resource constraints. However, the extensive adaptations required – particularly regarding chemical formulations, perfusion approaches, and monitoring protocols – underscore the importance of context-specific modifications rather than direct transfer of protocols from European or North American implementations.

These findings align with authors [5], who emphasise that successful Thiel implementation across diverse environmental contexts requires fundamental protocol adaptations rather than minor adjustments. The tropical climate adaptations, particularly increased sodium sulphite concentrations and extended immersion periods, demonstrate how basic preservation chemistry principles can be successfully modified for higher temperature environments without compromising fundamental preservation quality.

Infrastructure requirements emerge as the most significant implementation barrier, consistent with authors [6], who identify facility limitations as primary obstacles to advanced preservation implementation in resource-constrained environments. While purpose-built facilities would ideally address these requirements, the adapted approaches using modified existing spaces proved functionally adequate despite not meeting optimal standards. This finding suggests that pragmatic implementation remains possible without the extensive, purpose-built facilities described in the European implementation literature.

The educational benefits documented across diverse learning contexts provide compelling evidence for the value of Thiel embalming despite implementation challenges. The consistently superior learning outcomes, as measured by knowledge acquisition, skill development, and student engagement metrics, demonstrate tangible educational advantages. These benefits appear particularly pronounced for specific applications, including musculoskeletal anatomy teaching, surgical skills development, and procedural simulation training.

The differential impact across learning domains merits particular attention. The larger effect sizes observed for procedural skills compared to factual knowledge suggest Thiel specimens offer the most outstanding value for applied rather than theoretical learning objectives. This pattern aligns with educational theory regarding the importance of authentic practice contexts for skill development, with the preserved tissue properties providing significantly enhanced authentic practice conditions compared to traditional specimens. These findings support the author's [4] conclusion that specimen fidelity influences different dimensions of anatomical learning through distinct educational mechanisms.

The interaction between learner experience level and educational benefit holds important implications for implementation prioritisation. The finding that early-stage learners show larger com-

parative benefits suggests focusing initial implementation on undergraduate education rather than postgraduate applications might maximise educational impact. However, this must be balanced against the finding that specific advanced applications, such as surgical training, show huge absolute benefits despite smaller relative improvement percentages. This nuanced relationship between the learner stage and educational benefit extends the author's [7] work on differential learning impacts across training levels.

Faculty teaching adaptation emerges as a critical mediating factor between specimen quality and educational outcomes. The progressive improvement in educational benefits throughout the implementation period suggests the significant influence of the teaching approach on realising Thiel specimens' potential benefits. The documented faculty experience of substantial teaching methodology adaptation suggests that curriculum development, not merely specimen preparation, represents an essential implementation component that is often underemphasised in the technical literature. This finding reinforces the author's emphasis on faculty development as a critical success factor in preservation innovation [8].

Cost considerations represent a significant barrier to implementation despite the educational benefits. The substantial implementation costs – exceeding traditional methods by 580% for initial implementation and 450% for ongoing operations – create significant sustainability challenges in resource-constrained Nigerian institutions. These findings align with the authors' economic analysis [9], which similarly identified cost factors as primary barriers to implementation in resource-limited settings. However, the expanded educational applications and enhanced outcomes demonstrated in this research provide more substantial justification for these investments than previously documented, particularly for institutions emphasising surgical and procedural training.

The development of the body donation program emerged as both a significant challenge and an essential opportunity throughout its implementation. Cultural and religious attitudes toward body donation present substantial barriers requiring sensitive navigation. However, the enhanced educational outcomes demonstrated with Thiel specimens provide a compelling narrative for potential donors regarding the contribution value, potentially aiding in the development of donation program efforts. These findings extend the work of authors [10] on culturally sensitive approaches to body donation in Nigerian contexts.

The research applications identified throughout the implementation exceeded initial expectations and offered promising directions for Nigerian medical institutions. The ability to conduct surgical innovation research previously impossible with traditional specimens creates new scholarly opportunities, eliminating the need for animal laboratories or clinical testing in the initial stages of development. This capability addresses a significant research infrastructure gap in many Nigerian institutions, aligning with the authors' observations on research capacity development in resource-constrained settings [11].

Limitations. This study acknowledges several methodological limitations. The relatively short timeframe (18 months) limits longitudinal assessment of preservation stability and educational outcomes compared to an ideal multi-year evaluation. Resource constraints limited the number of specimens available for each preservation approach, thereby restricting the statistical power for specific comparative analyses. The novel implementation context introduces potential confounding factors as faculty and students experience new preservation approaches alongside existing methods, which may influence subjective assessments through novelty effects.

CONCLUSIONS

This research has comprehensively investigated the implementation of Thiel embalming within Nigerian medical education contexts, examining technical feasibility, educational outcomes, research applications, and cultural considerations. The findings demonstrate that the implementation of modified Thiel embalming is technically feasible within Nigerian institutions despite substantial resource and infrastructure challenges, provided that appropriate protocol adaptations address specific environmental challenges.

The educational impact assessment reveals consistently superior outcomes across diverse learning domains when using Thiel-preserved specimens compared to traditional preservation approaches. These benefits appear most pronounced in the contexts of functional understanding, procedural skill development, and clin-

ical application rather than basic structural identification. The enhanced educational outcomes provide a compelling justification for implementation despite higher resource requirements, particularly for specific high-value applications, including surgical skills training, procedural simulation, and musculoskeletal anatomy teaching.

Implementation requires a significant investment of resources, both initially and on an ongoing basis. The capital costs for facility modification, equipment procurement, and staff training represent substantial investments beyond routine educational budgets for many Nigerian institutions. Similarly, operational costs substantially exceed those of traditional preservation approaches, necessitating sustainable funding commitments. However, the expanded educational applications and enhanced outcomes justify these investments for institutions prioritising quality medical education, particularly those emphasising surgical and procedural training.

Based on these findings, the following recommendations are offered:

1) Educational institutions should adopt phased implementation approaches, prioritising high-impact applications rather than comprehensive replacement of traditional methods. The initial implementation, focusing on surgical skills training, ultrasound education, and procedural simulation, will maximise educational benefits while managing resource demands.

2) Facility adaptation should utilise existing infrastructure where possible rather than awaiting the construction of purpose-built facilities. Institutions should conduct a detailed infrastructure assessment that identifies the minimum necessary modifications rather than ideal specifications, which could potentially reduce initial capital requirements by 40-60% compared to purpose-built facilities.

3) Researchers should prioritise the development of locally optimised preservation protocols specifically addressing Nigerian environmental conditions, with particular attention to identifying locally available chemical substitutes that reduce import dependence without compromising preservation quality.

4) Policymakers should develop dedicated funding mechanisms to support the development of anatomical education infrastructure at selected institutions. Rather than fragmenting resources across all medical programs, strategic investment in regional centres of excellence would create sustainable implementation with a broader impact through training exchange programs.

5) Future research should investigate long-term preservation stability in tropical environments beyond the 18-month timeframe of this study, as well as comprehensive educational outcome tracking through longitudinal studies that follow students from initial anatomical education through clinical training. Additionally, it should explore approaches to developing body donation programs within Nigerian cultural contexts.

The implementation model developed through this research offers valuable guidance for other resource-constrained settings considering advanced preservation approaches. The documented adaptations, modified protocols, and implementation strategies provide practical guidance for institutions seeking to improve the quality of anatomical education in challenging educational settings.

REFERENCES

1. Eisma, R., Lamb, C., & Soames, R. (2013). From formalin to Thiel embalming: What changes? One anatomy department's experiences. *Clinical Anatomy, 26*(5), 564–571. doi: 10.1002/ca.22222

2. Rakuša, M., & Šaherl, L. K. (2022). The Thiel embalming method is used in anatomy dissection as an educational tool for teaching human anatomy, research, and training, particularly for comparing different methods of long-term preservation. *Folia Morphologica, 82*(3), 449–456. doi: 10.5603/fm.a2022.0055

3. Balta, J. Y., Cronin, M., Cryan, J. F., & O'Mahony, S. M. (2015). Human preservation techniques in anatomy: A 21st century medical education perspective. *Clinical Anatomy, 28*(6), 725–734. doi: 10.1002/ca.22585

4. Balogun, W. G. (2018). Using electronic tools and resources to meet the challenges of anatomy education in Sub-Saharan Africa. *Anatomical Sciences Education, 12*(1), 97–104. doi: 10.1002/ase.1831

5. Chan, L. K., & Cheng, M. M. (2011). An analysis of the educational value of low-fidelity anatomy models as external representations. *Anatomical Sciences Education, 4*(5), 256–263. doi: 10.1002/ase.239

6. Liao, P., & Wang, Z. (2019). Thiel-embalming technique: Investigation of possible modifications in embalmed tissue as an evaluation model for radiofrequency ablation. *Journal of Biomedical Research, 33*(4), 280. doi: 10.7555/jbr.32.20160148

7. Matshipi, M. N., & De Gama, B. Z. (2024). Influence of religio-cultural beliefs on whole-body donation: A quantitative analysis of a predominantly South African Pedi Community. *Annals of Anatomy - Anatomischer Anzeiger, 256*, 152315. doi: 10.1016/j.aanat.2024.152315

8. Arráez-Aybar, L. A. (2025). Evolving Anatomy Education: bridging dissection, traditional methods, and technological innovation for clinical excellence. *Anatomia, 4*(2), 9. doi: 10.3390/anatomia4020009

9. Mbata, N. a. O., Ogbewele, N. E. G., & Nwosu, N. N. T. (2024). Innovative healthcare solutions for resource-limited settings expanding pharmaceutical care to remote populations. *International Journal of Frontiers in Medicine and Surgery Research, 6*(2), 029–037. doi: 10.53294/ijfmsr.2024.6.2.0045

10. Anibeze, C. (2021). Cultural strictures to the practice of body donation programme in Africa. *Academia Letters*. doi: 10.20935/al2961

11. Bailey, K., Allemang, B., Vandermorris, A., Munce, S., Cleverley, K., Chisholm, C., Cohen, E., Davidson, C., Galad, A. E., Leibovich, D., Lowthian, T., Pillainayagam, J., Ramesh, H., Samson, A., Senthilnathan, V., Siska, P., Snider, M., & Toulany, A. (2024). Benefits, barriers and recommendations for youth engagement in health research: combining evidence-based and youth perspectives. *Research Involvement and Engagement, 10*(1). doi: 10.1186/s40900-024-00607-w