DOI: 10.30651/jqm.v9i01.21946

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LITERATURE REVIEW

Evaluating the effectiveness of Thiel embalming solution for preserving cadavers in anatomy and surgical education

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ARTICLE INFO

Submitted : *20th February 2024*
Accepted : *24th September 2024*
Published : *25th January 2025*

Keywords:
Embalming, Anatomy, Cadaver, Fixatives, Education

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ABSTRACT

Cadavers have played a crucial role in anatomy teaching, owing to their resemblance to the anatomical structures found in living individuals. To optimize the utilization of cadavers, embalming procedures that involve the application of chemical fixative agents are needed. The "soft embalming" approach, which involves various salts as fixating agents, was first developed by Walter Thiel. Although the Thiel solution has demonstrated efficacy in enhancing tissue elasticity, consistency, and color, a study is needed to find the most suitable for embalming with this solution to maximize its utility in the context of anatomy and surgical education. The study results show that the Thiel solution produces the best outcomes for its flexibility, uniformity, and color, which is optimal for anatomical and surgical teaching. The efficacy of Thiel's solution for preserving cadavers for educational intentions is noteworthy for the study of anatomy and surgical procedures. The advantageous characteristics of Thiel embalming include flexibility, consistency, and natural coloring. Nevertheless, it is crucial to consider the restrictions associated with preserving the brain, spinal cord, eye, and musculoskeletal tissues. In conclusion, the utilization of Thiel solution has proven to be an efficient embalming agent for preserving cadavers in the fields of anatomy and surgery education, besides brain, spinal cord, eye, and musculoskeletal systems, should be reconsidered.

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INTRODUCTION

Cadavers have been of utmost importance in anatomical studies for millennia due to their ability to represent the human body properly (Brenner, 2014; Kalthur et al., 2022). These instruments play a crucial role in several educational purposes, such as learning the fundamental anatomy, training in complex surgical procedures, and utilization of state-of-the-art imaging techniques such as CT and MRI scans (Eisma & Wilkinson, 2014; Kalthur et al., 2022; Schramek et al., 2013). However, cadavers encounter a significant obstacle in preserving their structural integrity because of post-mortem decomposition, principally caused by autolysis and putrefaction mechanisms (Hau et al., 2014).

Throughout history, embalming has been used to prolong and slow decomposition. The inclusion of formaldehyde in preservation procedures in the 18th century represented a notable development (Musiał et al., 2016). Initially developed as an antiseptic, the compound's capacity to form cross-links with proteins, leading to the deactivation of autolytic enzymes, rendered it a highly effective fixative (A. K et al., 2022). However, despite its proven effectiveness, formaldehyde has some disadvantages. It is known that the use of formaldehyde can cause stiffness, limited joint mobility, and discoloration of preserved corpses (Dan et al., 2020; Rakuša & Kocbek Šaherl, 2022). Limited success has been shown in minimizing these consequences, as exemplified by lowering the formaldehyde concentrations in Indonesia (Evelyn & Margiana, 2022; Kalanjati et al., 2012; Wijaya et al., 2021).

Research on potential preservatives is needed to determine the adverse effects associated with formaldehyde. In addition to using pure formaldehyde, other agents are used to reduce the concentration of formaldehyde. The "soft embalming" approach utilizing the Thiel Solution was invented by Professor Walter Thiel from Austria. This solution primarily comprises high-concentration ionic salts and other fixatives (Hachabizwa1 et al., 2020; Kocbek & Rakuša, 2017). For more than thirty years, this substitute for formaldehyde has been employed to maintain the consistency and color of cadavers(Kocbek & Rakuša, 2017). However, several disadvantages are associated with the embalming procedure, including the potential for loosening certain tissues, changes in the mechanical properties of tendons, and the need for additional embalming fluids to reverse brain softening.(Balta et al., 2015; Fessel et al., 2011; Miyake et al., 2020). Given the challenges, our study aims to investigate further the impacts of the distinct constituents of the Thiel embalming solution. Our objective is to gain a comprehensive understanding of the impacts of these substances on different organs to maximize their utilization in the fields of anatomy and surgical education.

Thiel Embalming Solution and Uses in Anatomical Study

The fixating agent, a disinfectant, and a preservation agent are the main components that help achieve the best results for an embalming solution. The Thiel embalming method involved the utilization of fixative compounds, namely 4-chloro-3-methylphenol, and multiple salts, such as ammonium nitrate, sodium sulfite, and potassium nitrate, inside the embalming fluid. Yet, there is a lack of precise understanding of the mechanisms via which salt functions as a fixative. However, it has been shown that these salts effectively facilitate the absorption of water within the tissue (Kocbek & Rakuša, 2017; Ottone et al., 2016). In addition to their function as fixatives, ammonium nitrate and potassium nitrate also act as nitrate donors for the formation of nitrosomyoglobin.

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Nitrate compounds in the form of NO react with myoglobin and metmyoglobin present in muscle tissue to form nitroso myoglobin. Converting nitrosomyoglobin to metmyoglobin occurs through an oxidation process, resulting in the red color of post-mortem muscles (Ottone et al., 2016; Sebranek & Bacus, 2007). The coalescence of salts and boric acid induces protein denaturation, enhancing muscles and joints' flexibility. Boric acid, in addition to formaldehyde, has been employed as an antibacterial agent. This solution demonstrates that the final concentration of formaldehyde is 0.8%, indicating a relatively low concentration. Ethylene glycol was used to maintain the tissue plasticity. These various components can enhance the flexibility and softness of the cadaver, diminish the presence of formalin odor, and contribute to an aesthetically pleasing coloration(Djembi et al., 2021; Ottone et al., 2016). The function of each component in Thiel solution is summarized in Table 1.

Thiel's embalming solution allows for improved joint flexibility, facilitating examination of the musculoskeletal structure of the cadavers. In addition to joints, muscles, tendons, and ligaments have been preserved for anatomical education. This phenomenon may be due to the partial denaturation of collagen and subsequent cross-linking promoted by the formaldehyde in the solution (Benkhadra et al., 2011; Fessel et al., 2011). Certain organs, including the brain, spinal cord, and eyes, do not exhibit optimal preservation outcomes when subjected to Thiel solution, as it has been observed to induce softening in these specific organs. Additional methods to address this issue must be implemented to mitigate this long-term deterioration. Additional preservatives may be required, such as preserving the brain through the sagittal plane, preserving the lungs through the trachea, and directly injecting the colon (Djembi et al., 2021; Miyake et al., 2020; Thiel, 2002).

Table 1. List of Thiel embalming components and their main function in the solution

No	Thiel Component	Function in Thiel Solution
1.	4-cloro-3methyphenol	Fixative agent and antifungal
2	Salts (Potassium nitrate, Ammonium nitrate, and sodium sulphite)	Fixative agent Nitrate donor for maintaining the redness of muscle colour (Potassium nitrate and ammonium nitrate only)
3.	Formaldehyde	Antimicrobial and fixative agent
4.	Boric acid	Antimicrobial and antiseptic
5.	Ethylene glycol	Maintaining the plasticity of tissue

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Another illustration of the Thiel solution's application in dissection is the identification of lymph vessels. Following the embalming process using Thiel solution, the corpse undergoes dissection of the thorax and abdomen to discover the thoracic duct. The subsequent injection of barium sulfate yields highly favorable outcomes. The visibility of the thoracic duct increases (Stouthandel et al., 2020). All the organs that are best and worst when embalmed using the Thiel solution are summarized in Table 2.

The Thiel solution is divided into two sets of solutions. One solution is for injection (primary embalming), and the other is for immersion. The injection solution needs formulas A and B, which are mixed with formaldehyde and sodium sulfite. Formula A consists of 3g boric acid, 20g ammonium nitrate, 5g potassium nitrate, 10 ml ethylene glycol mixed with 100 ml hot water. Formula B consists of 10 ml ethylene glycol and 1 ml 4-cloro-3methylphenol. The injection solution needs 14,3 liter of Formula A, 500 ml of Formula B, 300 ml of formaldehyde, and 700 g of sodium sulfite. This fluid will be injected into the body via an artery, the femoral or carotid artery. The immersion consists of 10 ml ethylene glycol, 2 ml Formula B, 3g boric acid, 10 g ammonium nitrate, 10 g potassium nitrate, 7 g sodium sulfate, and 2 ml formaldehyde. All of them will be mixed using 100 ml of hot water. The cadaver that has been injected will be put in the immersion solution for several months to years (Denis-Rodríguez & Aguirre-Gutiérrez, 2018; Kocbek & Rakuša, 2017; Ottone et al., 2016).

Table 2. List of organs that are best and worst embalmed using Thiel Solution

No.	Thiel embalming best for	Thiel embalming worst for
1.	Glands (ex: parotid, submandibular, thyroid and pancreas)	Brain and spinal cord
2.	Thoracic wall	Eye
3.	Heart	Musculoskeletal (biomechanic study)
4.	Blood vessels (Aorta and coronary artery)	
5.	Gaster and intestine	
6.	Kidney	
7.	Musculoskeletal (qualitative study)	

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The Use of Thiel Embalmed Cadaver (TEC) for Study in Nervous System

One of the notable advantages of using Thiel's solution in the embalming process is its contribution to medical and surgical education. The detrimental effects of this solution on the softening of the brain and spinal cord represent a significant disadvantage in the context of neurosurgical training. Adding agents such as formaldehyde, ethanol, and tap water can overcome this problem. The administration of this fluid through the ethmoid bone is a challenging technique (Thiel, 2002). The alternate methodology involves the administration of an extra solution through the ventricle of the brain, a procedure that has been empirically demonstrated to yield superior outcomes (Miyake et al., 2020).

A study of embalmed cadavers using Thiel's embalming solution for MRI-guided stereotactic procedures showed significant results. The brain condition was still satisfactory after 15 months of using the solution for embalming. This claim is supported by the sharp contrast between gray and white matter, which shows that brain plasticity can be preserved for surgical training (Ejamel et al., 2014). Additionally, the students use Thiel embalmed cadavers for regional nerve block training due to the convenient placement of the neck, upper extremities, and lower extremities, which provides a realistic sensory experience for training purposes (G. McLeod et al., 2010).

The Use of Thiel Embalmed Cadaver (TEC) for Study in organs of Head and Neck

The TEC is utilized in surgical procedures involving glands such as the parotid and submandibular gland, as well as in dissections of the ear and nose regions. The parotid and submandibular glands were observed to exhibit favorable texture and appearance(Humbert et al., 2022). In the context of nasal surgery, the softness of the ethmoid air cells has been shown to be lacking. However, tissue integrity was effectively preserved using freezing methods and formalin-only fixation methods. (Dubach et al., 2010; Humbert et al., 2022). The cadavers were preserved using the embalming techniques of oral and maxillofacial surgeons, and good results were achieved in terms of tissue appearance and softness in various procedures including osteotomy, bone grafting, and alveolar nerve.(Hölzle et al., 2012). Thiel embalming solution also gived an effective color preservation, which aids students in discerning the anatomical structures within the neck, including the thyroid and parathyroid glands(Eisma et al., 2011).

The Use of Thiel Embalmed Cadaver (TEC) for Study in Pulmonary and Cardiovascular System

According to the literature, their inherent flexibility facilitates the dissection of individual muscle layers in the neck region. In the field of thoracic, cardiac, and vascular surgery, this method of embalming opens new possibilities for the use of cadavers in education and research. Cardiopulmonary resuscitation (CPR) can be practiced using pig models or mannequins before using cadavers. Duhem et al. have initiated a study on the use of human cadaver models in the context of cardiopulmonary resuscitation (CPR). According to the study results, one of the researchers used an embalming solution for this purpose (Duhem et al., 2019). The use of preserved cadavers, especially those embalmed using the Thiel method, has served as a valuable model for cardiopulmonary resuscitation (CPR) research. The intrathoracic and thoracic compressions are very similar to what patients experience in out-of-hospital cardiac arrest. Additionally, airway patency can be assessed using intubation techniques and quantified using capnography. The use of

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TECs for intubation and chest compression procedures enhances realism. However, TECs are not suitable for hemodynamic testing (Charbonney et al., 2018; Grieco et al., 2019).

In the pilot trial, thoracotomy was employed for cardiac surgery using a cadaver that had been embalmed with the Thiel method. This approach can effectively facilitate educational training in the field of thoracotomy, catering to anesthetists, physicians, and surgeons (Puchwein et al., 2015). In addition to open thoracotomy, the use of Thiel-embalmed cadavers can serve as an advanced model for coronary artery bypass graft training. This methodology has the potential to facilitate the preparation of a variety of coronary artery anastomoses and, therefore, represents a valuable opportunity to improve proficiency in bypass techniques (Bouma et al., 2015).

In their work on endovascular surgery in the Aorta, the TEC model provided a highly suitable representation of the anatomical and physiological aspects relevant to this research. The utilization of extracorporeal ante-grade pulsatile flow offers several advantages in terms of realism compared to the use of animal models or virtual models. In this paradigm, several radiology examinations, such as ultrasonography (USG) and palpation, can be conducted to assess the artery (H. McLeod et al., 2017).

The Use of Thiel Embalmed Cadaver (TEC) for Study in Abdominal Region

The utilization of TEC has gained significant recognition in gastroenterology, particularly in colorectal surgery. These cadavers have proven to be highly valuable for laparoscopic surgical procedures due to their well-preserved state. However, it is worth noting that the widespread adoption of TEC in this context remains limited around the globe(Isabel Prieto-Nieto et al., 2021). Besides its application in gastroenterology, this model has been used primarily in renal surgery, such as partial nephrectomy and kidney transplantation. Studies of laparoscopic nephrectomy have shown that the color and texture of the abdomen and kidneys are more like those of recently preserved cadavers.(Prasad Rai et al., 2012). Renal kidney transplantation offers similar benefits to kidney resection without the need for a surgical approach involving excessive bleeding. Therefore, the cadaver embalmed by Thiel was selected as the optimal model (Cabello et al., 2015; Coloma et al., 2020).

The Use of Thiel Embalmed Cadaver (TEC) for Study in Musculoskeletal System

Thiel's solution has previously been reported to increase joint flexibility, prompting further research on the biomechanical properties of various anatomical structures such as bone, skeletal muscle, tendons, and ligaments. The purpose of this study was to determine whether Thiel embalmed cadavers could be an effective model for orthopedic surgical training. Thiel's solution produced unfavorable tendon preservation outcomes as evidenced by quantitative analysis, which showed lower elastic moduli than fresh-frozen cadavers. However, qualitative studies have shown that Thiel's solution is similar to fresh-frozen cadavers (Fessel et al., 2011; Joy et al., 2015; Völlner et al., 2017).

The qualitative advantage of using TEC as anatomical models for surgery simulation has been demonstrated in studies involving flexor tendon repair simulations in both cadaver and porcine models (Hassan et al., 2015). Biomechanical studies performed on metatarsal bone preserved using the Thiel method showed a decrease in strength compared to bones that were either freshly frozen or preserved with formaldehyde alone. This finding suggests that one of the shortcomings of the Thiel solution

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is its unsuitability for biomechanical research and development.(Gatt et al., 2016, 2021). The biomechanical research on ankle tendons and ligaments has also shown a similar drawback, wherein a decrease in elastic modulus was seen (Liao et al., 2015). The Thiel method has demonstrated certain merits in qualitative investigations within musculoskeletal studies. However, it presents several drawbacks when used in quantitative studies, particularly in surgery and biomechanical analysis.

This study found some limitations with the use of Thiel's embalming solution. Biomechanical studies have shown that changes in tendons, ligaments, and bones lead to musculoskeletal applications. Bodies preserved by the Thiel method have limited usability. Over time, the effectiveness of the embalming solution may decrease, resulting in changes in tissue properties. In addition, the high cost of using this solution places a burden on medical education providers.

In brief, the Thiel embalming solution presents various benefits for anatomical investigations and surgical simulations. However, it is crucial to acknowledge its inherent constraints, such as its inapplicability to biomechanical inquiries, the considerable expenses associated with its upkeep, the limited duration of its use, the requirement for supplementary embalming procedures for certain organs, the restricted global acceptance it has garnered, the environmental implications it poses, the ethical considerations it raises, and the existence of alternative preservation techniques. Researchers and educators must evaluate their specific requirements and available resources thoroughly when deciding to employ this embalming option.

CONCLUSION

This solution has been proven to be an efficient embalming agent for preserving cadavers in the fields of anatomy and surgery education, but it needs to be reconsidered when preserving some organs, such as the brain, spinal cord, eye, and musculoskeletal systems.

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