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Saturated Salt Solution Method: A Useful Cadaver Embalming for Surgical Skills Training

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Abstract: This article evaluates the suitability of cadavers embalmed by the saturated salt solution (SSS) method for surgical skills training (SST).

SST courses using cadavers have been performed to advance a surgeon's techniques without any risk to patients. One important factor for improving SST is the suitability of specimens, which depends on the embalming method. In addition, the infectious risk and cost involved in using cadavers are problems that need to be solved.

Six cadavers were embalmed by 3 methods: formalin solution, Thiel solution (TS), and SSS methods. Bacterial and fungal culture tests and measurement of ranges of motion were conducted for each cadaver. Fourteen surgeons evaluated the 3 embalming methods and 9 SST instructors (7 trauma surgeons and 2 orthopedists) operated the cadavers by 21 procedures. In addition, ultrasonography, central venous catheterization, and incision with cauterization followed by autosuture stapling were performed in some cadavers.

The SSS method had a sufficient antibiotic effect and produced cadavers with flexible joints and a high tissue quality suitable for SST. The surgeons evaluated the cadavers embalmed by the SSS method to be highly equal to those embalmed by the TS method. Ultrasound images were clear in the cadavers embalmed by both the methods. Central venous catheterization could be performed in a cadaver embalmed by the SSS method and then be affirmed by x-ray. Lungs and intestines could be incised with cauterization and autosuture stapling in the cadavers embalmed by TS and SSS methods.

Cadavers embalmed by the SSS method are sufficiently useful for SST. This method is simple, carries a low infectious risk, and is relatively of low cost, enabling a wider use of cadavers for SST.

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Abbreviations: FAS = formalin solution, ROM = range of motion, SSS = saturated salt solution, SST = surgical skills training, TS = Thiel solution.

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INTRODUCTION

Surgical techniques are constantly advancing; thus, surgeons require training and practice to achieve mastery of the new procedures. The use of cadavers for surgical skills training (SST) has been compared with that of other methods such as live animals and low and high-fidelity simulators,[1] and the benefits of anatomic fidelity and the ability to assess operative outcome are balanced by the difficulty and cost of setting up such a program.[2] An important factor when considering the use of human cadavers for SST is their preservation. A large number of studies use fresh-frozen cadavers.[3–12] Fresh or fresh-frozen cadavers initially ''exhibit life-like color, softness, and pliability.''[3] However, fresh cadavers also present a myriad of problems, including the requirement of freezers for storage and limited work time (a few weeks at the most) because of rapid putrefaction following thawing. The risk of infection from unembalmed tissue is also significant.[13]

The alternative to fresh cadavers is embalmed cadavers.[14] Embalming fluids, despite their chemical properties, should provide a good long-term structural preservation of organs and tissues together with prevention of overhardening and retention of color of tissues and organs.[15] They should also prevent desiccation and fungal or bacterial growth.[16] Reduction of both potential biohazards and environmental chemical hazards is also necessary.[16] Since the first documented embalming of a human cadaver using formalin solution (FAS), which is thought to have occurred in 1899, very little has changed in the basic chemistry or technique of formalin preservation of human cadavers over 100 years later.[16] FAS is bactericidal, fungicidal, and insecticidal (in descending efficiency). The extensive use of FAS as a curing and preserving agent is based on the fact that FAS has excellent antiseptic properties and thus prevents the entry of decay organisms. In addition, it tans tissues without destroying their delicate structure.[17] Although FAS is an excellent tissue fixative, its use is generally associated with extreme rigidity.[18] The relatively high levels of formalin thus harden tissues[19] and have been found to severely affect the quality of cadaveric tissue, particularly soft tissues.[20] Although FAS remains the most frequently used embalming solution,[21] there has been a paucity of literature concerning the different embalming methods for use in surgical skill training[14] in recent years. For example, Thiel[22,23] presented a delicate method for ''the preservation of the whole corpse with natural colors.'' As stated by the author, this method has the advantage of meeting high standards of preservation without releasing harmful substances into the environment. In fact, Thiel solution (TS)-embalmed cadavers have been widely appraised for postgraduate hands-on workshops for several medical disciplines.[24–33] Several reports have shown that cadavers conserved by this method present a texture and color very close to that of living individuals, and several applications in areas such as surgery, echography, regional anesthesia, and anesthesiology research on the airways have been described.[26,28–30,34] Nevertheless, his method is quite complicated and includes several problematic and expensive substances during the process of preservation itself. In addition, TS-embalmed cadavers have been known to have the drawbacks of muscular disintegration and limited time for dissection.[16]

On the contrary, Logan[35] described a cadaver preservation procedure, which differs in several important features from methods in common use. His solution comprised alcohol, glycerine, phenol, and low levels of formaldehyde. Coleman and Kogan[15] made a simple modification to this embalming mixture with its high salt component and relatively low formalin. They used almost the same chemicals (they replaced alcohol with isopropyl alcohol) but added a vast amount of sodium chloride. They argued that the high salt content retained in the tissues prevented any further significant desiccation and the cadavers were thus excellently preserved, they had minimal structural distortion, their tissues were supple, there was little desiccation, and the colors remained natural. Moreover, common salt is readily available and is very cheap.[15]

Although these characteristics of the ''saturated salt solution'' (SSS) method by Coleman and Kogan seem to be ideal for SST, discussion of this method and its use for anatomical teaching has been limited. In addition, to our knowledge, there has been no follow-up report on their method, not only for SST but also for anatomical teaching. The present study aimed to investigate the suitability of the SSS method for SST by comparing it with other commonly used embalming methods.

METHODS

Information on Cadavers

Six cadavers (No. 201321, male aged 93 years who died of senile decay; No. 201329, female aged 88 years who died of aplastic anemia; No. 201408, male aged 79 years who died of lung cancer; No. 20409, female aged 94 years who died of senile decay; No. 2014110, female aged 85 years who died of septic shock; and No. 201411, female aged 84 years who died of pneumonia) were used for this study. The cadavers were donated to Tokyo Medical University, Tokyo, Japan. Before they died, the donors signed documents agreeing to body donation and its use for clinical studies. The format of the document is within the expectation of the Japanese law ''Act on Body Donation for Medical and Dental Education.''

Embalming Methods for Cadavers

The six cadavers were embalmed by 3 different methods: FAS (FAS1, No. 201321, and FAS2, No. 201329), TS (TS1, No. 201410, and TS2, No. 201411), and SSS (SSS1, No. 201408, and SSS2, No. 201409) methods. The composition of each embalming solution is shown in Table 1. FAS consisted of 20% formaldehyde, phenol, glycerine, and water. TS was prepared through several steps as follows: stem solutions A, B, and C were made, in this order. The stem solutions were then mixed with propylene glycol and hot water, resulting in the stock solution. Before use for embalming cadavers, the stock solution was mixed with sodium sulfite, 20% formaldehyde, morpholine, and ethanol.[22,23] SSS consisted of sodium chloride, 20% formaldehyde, phenol, glycerine, isopropyl alcohol, and water.[15] The total amount of each solution was as reported in each of the previous articles. The embalming process consisted of making a 3-cm incision in the femoral triangle or posterior cervical triangle; the femoral artery or common carotid artery was then cannulated, one cannula cephalad and one toward the feet. The cannulae were connected to a Porti boy pump, and approximately 1.0 L of embalming fluid was injected into the leg, the cannula was locked off, and 5.0 L was then injected through the cephalad-placed cannula. The cannulae were left in place overnight and then removed the following day, following which the femoral artery or the common carotid artery was ligated and the incision was closed. Once embalming was completed, the body was placed in a sealed plastic body bag and stored at room temperature.

Bacterial and Fungal Culture Tests

To investigate the infectious risk from each cadaver, bacterial and fungal culture tests were performed. The samples were obtained from the pharynx and the rectum using cotton swabs before embalming cadavers and then 14 days after embalming. In addition, samples of pleural fluid and ascites were collected during surgical training. The tests were performed in the clinical laboratory of Tokyo Medical University Hospital.

Measurement of ROM of Joints

An orthopedist measured range of motion (ROM) of the joints on both the right and left sides of each recumbent cadaver. ROM was tested using a standard goniometer (Baseline 15 cm).

Assessment of Each Embalming Method and the Suitability for Surgeon Surgical Training

Visual and tactile assessment, skin incision and suture, vessel ligation and suture, decollement, and usefulness for SST of cadavers embalmed by each method were evaluated using a 5-point rating scale [1 = completely different, 2 = somewhat different, 3 = neither different or similar, 4 = somewhat similar,

TABLE 1. Composition of Three Different Embalming Solutions

FAS		TS		SSS	
Solution	**Amounts, L**	**Solution**	**Amounts**	**Solution**	**Amounts**
20% Formaldehyde	4.0	A. Stem solution		Sodium chloride	20 kg (saturated)
Phenol	0.4	4-Chloro-3-methylphenol	66 g	20% Formaldehyde	1.0 L
Glycerine	1.0	Propylene glycol	0.66 L	Phenol	0.2 L
Water	14.6			Glycerine	0.5 L
Total	22.0	B. Stem solution B		Isopropyl alchol	4.0 L
		Ammonium nitrate	2500 g	Water	19.3 L
		Hot water	4 L	Total	25.0 L
		C. Stem solution C			
		Boric acid	370 g		
		Potassium nitrate	620 g		
		Hot water	5 L		
		D. Stock solution			
		Stem solution A	0.66 L		
		Stem solution B	4 L		
		Stem solution C	5 L		
		Propylene glycol	3.7 L		
		Hot water	3.3 L		
		E. Final solution			
		Stock solution	16.66 L		
		Sodium sulfite	800 g		
		20% Formaldehyde	0.6 L		
		Morpholine	0.3 L		
		Ethanol	1.3 L		
		Total	18.86 L		

FAS = formalin solution, SSS = saturated salt solution, TS = Thiel solution.

and 5 = completely similar, from living patients] by 14 surgeons. In addition, the instructors of our SST course (7 trauma surgeons and 2 orthopedists), who had 16.1 ± 6.72 (average ± standard deviation) years of clinical experience, performed 21 procedures on the cadavers [basic technique: 1 = cricothyroidotomy, 2 = chest tube insertion; thoracic trauma: 3 = pericardial window technique, 4 = left anterior thoracotomy and aortic clamp, 5 = bilateral anterior thoracotomy (clam shell), 6 = pulmonary hilar clamp, 7 = pulmonary injury, 8 = atrial injury, 9 = ventricular injury; vascular trauma: 10 = exposure of femoral vessels, 11 = exposure of neck vessels, 12 = vascular repair (direct suture, patch repair, end-to-end anastomosis, shunting); abdominal trauma: 13 = trauma laparotomy, 14 = portal triad clamp (Pringle maneuver), 15 = liver package, 16 = left medial visceral rotation (Mattox maneuver), 17 = right medial visceral rotation (Cattel–Braasch maneuver), 18 = nephrectomy, 19 = abdominal damage control technique, 20 = pelvic package; and injuries to the extremities: 21 = fasciotomy of the lower extremity] and ranked the 3 embalming methods on the basis of the usefulness for mastering each procedure.

Statistical Analyses

Evaluation and analysis of all data were performed using Prism 6.0d for Macintosh (GraphPad Software, Inc, San Diego, CA) with the Kruskal–Wallis tests and Dunn multiple comparison tests. P values <0.05 were considered to be statistically significant.

Ultrasonography

Before SST, a clinical technologist performed ultrasonography on each cadaver. The ultrasound equipment used in this examination was TUS-A500 (Aplio, Toshiba Medical Systems Corporation, Tochigi, Japan) with a convex probe (PVT-375BT, 3.75-MHz center frequency). The imaging mode used was wideband harmonic imaging.

Central Venous Catheterization

Before SST, an anesthesiologist attempted to inset central venous catheterization under ultrasonic guidance. The linear probe used was PLT-1005BT, 10.0-MHz center frequency. As cannulae had been inserted into the right common carotid arteries in some cadavers to inject the embalming solution, the left internal jugular veins were used for central venous catheterization. The catheter used was the Microneedle Seldinger Kit (12G × 20 cm; Nippon Sherwood, Tokyo, Japan). After SST, a chest anterior–posterior x-ray was performed using a portable x-ray device (DR CALNEO Go; Fujifilm Corporation, Tokyo, Japan).

Incision With Cauterization and Autosuture Stapling

After SST, an incision with cauterization and autosuture stapling was made on the lungs and intestines in the TS and SSS-embalmed cadavers. The cauterization device used in this examination was an Erbe Unit (Erbe APC-300 and ICC-200; Erbe Elektromedizin Ltd., Tübingen, Germany). The autosuture-stapling devices were the GIA single-use reloadable staplers (GIA6038S; Covidien Co., Mansfield, MA) for the lungs and the Proximate Linear Cutter (TLC75; Johnson & Johnson, Tokyo, Japan) for the intestines.

RESULTS

Evaluation of Infectious Risk

Bacterial and fungal culture tests revealed that FAS could kill bacteria and fungi in the 2 FAS-embalmed cadavers (FAS1 and 2 in Table 2). In one TS cadaver, 14 days after embalming (TS1 in Table 2), some bacteria and/or fungi could be still detected in the pharynx and rectum; however, this was not observed in the second cadever (TS2 in Table 2). Similar to the TS method, the SSS method appeared to kill bacteria and fungi in one cadaver (SSS1 in Table 2) but to a lesser degree in the second one (SSS2 in Table 2). Pleural fluid and ascites samples obtained during SST from all cadavers contained no bacteria or fungi (Table 2).

Evaluation of ROM of Joints

In all joints, ROMs of the FAS-embalmed cadavers were statistically lesser than those of the TS embalmed (FAS vs TS in Table 3). All ROMs of the SSS-embalmed cadavers tended to be better than those of the FAS embalmed, and there were significant differences in some movements (FAS vs SSS in Table 3). On the contrary, there was no significant difference in ROMs between the TS and SSS-embalmed cadavers (TS vs SSS in Table 3).

Assessment of Each Embalming Method by Surgeons

In both visual and tactile assessments, the surgeons felt that the FAS-embalmed cadavers were more significantly divergent from living patients than the TS or SSS embalmed (Figure 1A and B). In addition, for each procedure, the FAS-embalmed cadavers were evaluated to be significantly less suitable than the TS and SSS embalmed (Figure 1C–G). The SSS-embalmed cadavers did not show statistically lesser values than the TS-embalmed cadavers for all these items. In the surgical skills assessments shown in Table 4, the FAS-embalmed cadavers were ranked the lowest in terms of suitability for all techniques, and no significant difference was found between the TS and SSS-embalmed cadavers (Table 4). Finally, the TS and SSS-embalmed cadavers were evaluated to be equally useful for SST, and no surgeon recognized FAS-embalmed cadavers as more useful (Figure 1H).

Abdominal Ultrasonography

The ultrasound images in the FAS-embalmed cadavers were not clear, and it was difficult to detect the heart, liver, and kidneys (Figure 2A and D). However, those organs could be clearly detected in the TS and SSS-embalmed cadavers, with no difference between the 2 methods (Figure 2B, C, E, and F).

Central Venous Catheterization

Since the blood in the FAS-embalmed cadavers had congealed, central venous catheterization was not performed. By the TS method, the blood gelled and the ultrasound image of the vascular cavity was not of low density as expected (Figure 3A); it was therefore difficult to insert the catheter from the internal jugular vein. However, the ultrasound image in the SSS-embalmed cadavers was very clear (Figure 3B). Because the SSS method liquefied the blood, the catheter could be inserted from the internal jugular vein (Figure 3C), and by pulling back on the plunger of the syringe actively, backflow from the catheter could be confirmed. The chest x-ray image after SST was clear in the SSS-embalmed cadavers, and pneumothorax that occurred after thoracotomy could be easily observed (shown by an asterisk in Figure 3C). The tip of the catheter could be found in the superior vena cava (shown by an arrow in Figure 3C).

Incision With Cauterization and Autosuture Stapling

After insertion of a tracheotomy tube, the lungs could be ventilated in the TS and SSS-embalmed cadavers but not in the FAS embalmed. The lungs could be easily incised and sutured using the autosuture-stapling devices (Figure 4A and B). During intestinal amputation, the mesentery could be incised using the cauterization device in both the TS and SSS-embalmed cadavers (Figure 4C and D) as same as living patients. The intravascular fluid was gel-like in the TS-embalmed cadavers and serous-like transparent in the SSS embalmed. The mesenteries could be incised with cauterization using the electrosurgical knife both in the TS and SSS-embalmed cadavers. Similar to the lungs, the intestines could be easily incised and sutured using the autosuture-stapling devices (Figure 4C and D).

TABLE 2. Results of Bacterial and Fungal Culture Tests on Cadavers Following 3 Different Embalming Methods

		Cadavers											
		FAS1		FAS2		TS1		TS2		SSS1		SSS2	
Samples	Tests	Before Embalming	After 14 d	Before Embalming	After 14 d	Before Embalming	After 14 d	Before Embalming	After 14 d	Before Embalming	After 14 d	Before Embalming	After 14 d
Pharynx	Bacteria	3+	–	3+	–	3+	3+	3+	–	3+	1 colony	3+	–
	Yeast-like fungi	3+	–	3+	–	3+	2+	2+	–	3+	–	3+	–
Rectum	Bacteria	3+	–	3+	–	3+	1+	3+	–	3+	1+	3+	–
	Yeast-like fungi	3+	–	3+	–	3+	–	3+	–	3+	–	3+	–
Pleural fluid	Bacteria	n/a	–	n/a	–	n/a	–	n/a	–	n/a	–	n/a	–
	Yeast-like fungi	n/a	–	n/a	–	n/a	–	n/a	–	n/a	–	n/a	–
Ascites	Bacteria	n/a	–	n/a	–	n/a	–	n/a	–	n/a	–	n/a	–
	Yeast-like fungi	n/a	–	n/a	–	n/a	–	n/a	–	n/a	–	n/a	–

FAS = formalin solution, n/a = not available, SSS = saturated salt solution, TS = Thiel solution.

TABLE 3. Range of Motion of Joints in Cadavers Following Embalming by 3 Different Methods

		Cadavers												Significant Differences		
		FAS1		FAS2		TS1		TS2		SSS1		SSS2				
Joints	Movements	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	FAS vs TS	FAS vs SSS	TS vs SSS
Shoulder joint	Flexion	30	20	10	10	160	150	150	150	110	90	95	100	**	ns	ns
	Abduction	45	50	30	30	110	130	150	150	110	100	90	90	**	ns	ns
	Internal rotation	45	80	75	60	80	80	90	90	80	80	80	70	*	ns	ns
	External rotation	15	10	−50	−45	60	65	50	50	20	40	15	15	**	ns	ns
Elbow joint	Extension	0	−10	−20	−10	10	10	0	0	−10	0	0	0	*	ns	ns
	Flexion	130	130	80	80	15	150	140	120	110	135	95	95	ns	ns	ns
Wrist joint	Extension	20	0	30	10	70	75	40	30	15	35	45	10	ns	ns	ns
	Flexion	45	30	25	10	85	90	50	30	30	25	40	50	ns	ns	ns
	Internal rotation	20	20	40	50	90	90	90	70	80	70	35	50	*	ns	ns
	External rotation	45	80	30	20	90	90	40	50	70	90	75	60	ns	ns	ns
Hip joint	Extension	−20	0	0	0	0	0	0	0	−5	−5	0	0	ns	ns	ns
	Flexion	30	20	10	10	100	95	110	100	45	50	50	75	**	ns	ns
	Internal rotation	−40	0	5	5	25	20	60	20	15	0	10	10	*	ns	ns
	External rotation	50	15	5	5	45	60	20	70	15	40	30	50	ns	ns	ns
	Adduction	−10	15	10	10	20	15	20	20	15	10	10	5	ns	ns	ns
	Abduction	30	15	5	5	30	30	25	25	5	25	30	30	ns	ns	ns
Knee joint	Extension	−30	−10	0	0	0	−5	0	0	−20	−25	−15	−15	ns	ns	ns
	Flexion	45	20	5	5	150	150	150	130	50	75	95	85	**	ns	ns
Ankle joint	Extension	0	−30	−30	−50	10	15	−10	−10	−30	−30	−45	−35	ns	ns	*
	Flexion	0	30	30	50	40	45	35	35	35	35	55	45	ns	ns	ns

FAS = formalin solution, SSS = saturated salt solution, TS = Thiel solution.
ns = not significant ($P > 0.05$).
* $0.01 < P < 0.05$.
** $P < 0.01$.

DISCUSSION

In this study, we showed that cadavers embalmed by the SSS method had sufficient antibiotic protection (Table 2), their joints remained flexible (Table 3), and their soft tissue quality was acceptable for SST (Table 4). The surgeons evaluated the SSS-embalmed cadavers as being highly equal to the TS embalmed (Figure 1). Ultrasound images were clear in both the TS and SSS-embalmed cadavers (Figure 2). Central venous catheterization could be inserted in the SSS-embalmed cadaver and then be affirmed by x-ray (Figure 3). Lungs and intestines could be incised with cauterization and closed using an auto-suture-stapling device in TS and SSS-embalmed cadavers (Figure 4). This is the first report documenting that SSS-embalmed cadavers are suitably preserved for SST.

Embalming of the dead has been practiced since ancient times. Since the Egyptians successfully embalmed bodies and the earliest Biblical texts refer to the practice, salt appears to have been used in the embalming process.[36] Ambroise Paré (1510–1590), who is considered as one of the fathers of surgery, a pioneer in surgical techniques, and an anatomist, described that he used ‘‘common salt’’ as a component of his embalming solution.[36] Thus, the use of common salt in embalming cadavers for advancing surgical skills has a long history. On the contrary, the extensive use of formalin as a curing and preserving agent is based on its excellent antiseptic properties, which prevent the entry of putrefying organisms; it also tans tissues without destroying their delicate structure.[17] With reference to Coleman and Kogan,[15] the SSS used in this study contained just 0.8% formaldehyde (Table 1). Nevertheless, bacterial and fungal culture tests proved that the SSS has a bacteriocidal effect (Table 2). Considering the presence of multiple bacteria and fungi before embalming, SSS-embalmed cadavers are considered to be no less safe than FAS-embalmed cadavers. At least, it is undoubted that they have lower infectious risks and are less perishable than fresh-frozen cadavers.

Softness of tissue and joints in a cadaver is an important factor for SST. Relatively high levels of formalin hardens tissues[17] and have been found to severely affect the quality of cadaveric tissue, particularly soft tissue, which has an effect on joint flexibility.[20] Formalin acts by crosslinking several proteins chemically by inserting a methylene bridge ($-CH_2-$), resulting in fixation or a tanning-type action.[38] To reduce the formalin concentration, various embalming methods have been developed, including the TS method (ie, 0.6% formaldehyde) (Table 1). It is well known that TS-embalmed cadavers have a joint flexibility comparable with that of fresh cadavers.[14] Our results showed that the joints of SSS-embalmed cadavers (ie, 0.8% formaldehyde) tended to be softer than those of FS embalmed (ie, 4.4% formaldehyde) but harder than those of TS embalmed (Table 3). However, the surgeons evaluated SSS and TS-embalmed cadavers as the same (Figure 1). Furthermore, the evaluation of SSS-embalmed cadavers did not vary much between surgeons in comparison with that of TS-embalmed cadavers. It is known that TS-embalmed specimens presented considerable changes in their histological appearance.[29,37] Benkhadra et al[29] considered that the flexibility of TS-embalmed cadavers may be because of a considerable fragmentation of muscle proteins. Fessel et al[37] argued that TS-preserved tissues indicated a different collagen fiber/collagen network and concluded that TS-embalmed tendons did not faithfully represent the biomechanical characteristics of fresh-frozen tendons. Our results suggested that the visionary and tactile feelings of TS-embalmed cadavers were not necessarily close to those of living

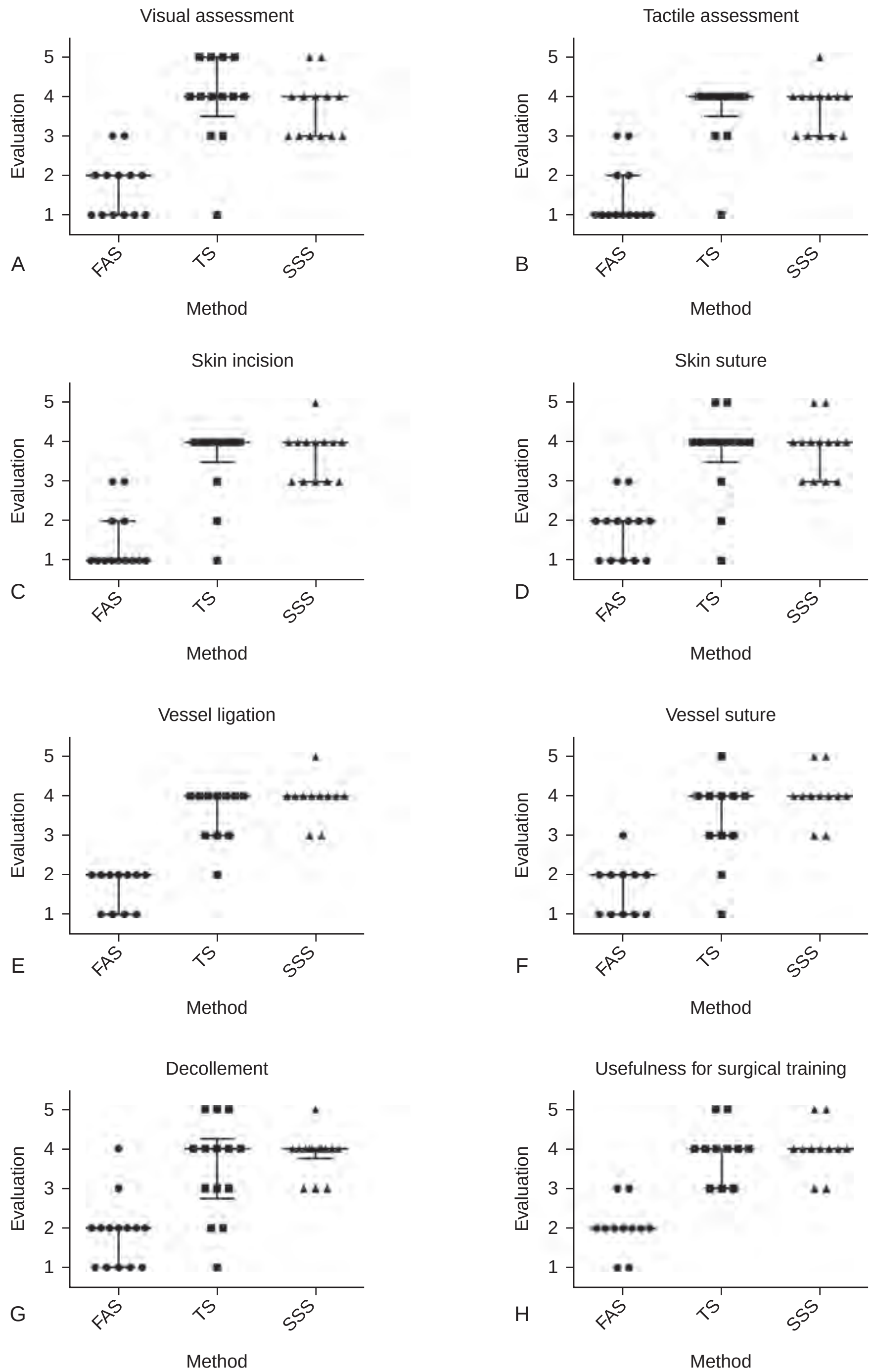

FIGURE 1. Assessment of 3 different embalming methods by surgeons. Visual and tactile assessments show the similarity to living patients. The other items show the facility of each procedure. All items are evaluated on a 5-point rating scale (1 = completely different, 2 = somewhat different, 3 = neither different nor similar, 4 = somewhat similar, and 5 = completely similar, from living patients). The line and error bars in each data set indicate the medians with interquartile ranges. FAS = formalin solution, SSS = saturated salt solution, TS = Thiel solution.

subjects. In the present study, some surgeons commented that TS-embalmed cadavers were too soft in several regions, for example, the heart and the kidney. On the contrary, the SSS-embalmed cadavers were certainly viewed as being too hard by some surgeons; however, their elasticity was favored by most in comparison with that of TS embalmed. In particular, 1 surgeon pointed out that membrane peeling was more problematic in TS-embalmed cadavers than in FAS-embalmed cadavers.

Because it is advantageous for surgeons to study the body interior of a cadaver before operation, ultrasonography was initially used in this study to examine cadavers. Schramek et al[38] reported that ultrasound was not suitable

TABLE 4. Suitability of Cadavers for Use in Surgical Skills Training Following Embalming by 3 Different Methods

		Averages of Ranks			Rank Sums			Significant Differences		
	N	FAS	TS	SSS	FAS	TS	SSS	FAS vs TS	FAS vs SSS	TS vs SSS
Basic technique										
1) Cricothyroidotomy	9	3.00	1.44	1.44	23.0	9.5	9.5	***	***	ns
2) Chest tube insertion	9	3.00	1.56	1.33	23.0	10.5	8.5	**	***	ns
Thoracic trauma										
3) Pericardial window technique	9	3.00	1.33	1.56	23.0	8.5	10.5	***	**	ns
4) Left anterior thoracotomy and aortic clamp	9	3.00	1.22	1.67	23.0	7.5	11.5	****	**	ns
5) Bilateral anterior thoracotomy (Clam shell)	9	3.00	1.33	1.67	23.0	8.0	11.0	****	**	ns
6) Pulmonary hilar clamp	9	3.00	1.22	1.78	23.0	7.0	12.0	****	**	ns
7) Pulmonary injury	9	3.00	1.11	1.89	23.0	6.0	13.0	****	*	ns
8) Atrial injury	8	3.00	1.50	1.50	20.5	8.5	8.5	***	***	ns
9) Ventricular injury	8	3.00	1.50	1.50	20.5	8.5	8.5	***	***	ns
Vascular trauma										
10) Exposure of femoral vessels	9	2.80	1.44	1.78	21.0	9.0	12.0	**	*	ns
11) Exposure of neck vessels	9	2.78	1.44	1.78	21.0	9.0	12.0	**	*	ns
12) Vascular repair (direct suture, patch repair, end-to-end anastomosis, and shunting)	9	3.00	1.44	1.56	23.0	9.0	10.0	***	***	ns
Abdominal trauma										
13) Trauma laparotomy	8	2.88	1.50	1.50	20.5	7.0	10.0	**	**	ns
14) Portal triad clamp (Pringle maneuver)	8	3.00	1.25	1.63	20.5	7.0	10.0	***	**	ns
15) Liver package	8	3.00	1.50	1.38	20.5	9.0	8.0	**	***	ns
16) Left medial visceral rotation (Mattox maneuver)	8	3.00	1.63	1.25	20.5	10.0	7.0	**	***	ns
17) Right medial visceral rotation (Cattel–Braasch maneuver)	8	3.00	1.63	1.25	20.5	10.0	7.0	**	***	ns
18) Nephrectomy	8	3.00	1.63	1.38	20.5	9.5	7.5	**	***	ns
19) Abdominal damage control technique	8	3.00	1.63	1.38	20.5	9.5	7.5	**	***	ns
20) Pelvic package	8	3.00	1.22	1.78	23.0	7.0	12.0	****	**	ns
Extremity injury										
21) Fasciotomy of the lower extremity	9	3.00	1.33	1.44	23.0	9.0	10.0	***	***	ns

The instructors ranked each embalming method on the basis of usefulness for mastering each procedure.
FAS = formalin solution, SSS = saturated salt solution, TS = Thiel solution.
ns = not significant ($P > 0.05$).
* $0.01 < P < 0.05$.
** $0.0001 < P < 0.01$.
*** $0.00001 < P < 0.001$.
**** $0.000001 < P < 0.00001$.

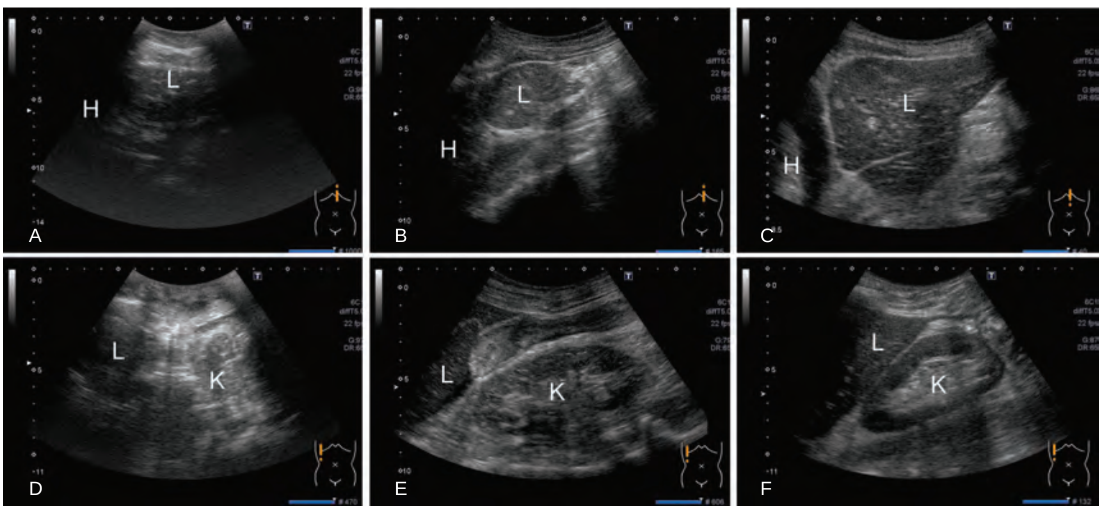

FIGURE 2. Abdominal ultrasonography in cadavers embalmed by 3 different methods. (A–C) Longitudinal images through the heart (H) and liver (L). (D–F) Longitudinal images through the left and right kidneys (K). (A) and (D) are from the formalin solution-embalmed cadaver (1 cadaver). (B) and (E) are from the Thiel solution-embalmed cadaver (1 cadaver) before surgical skills training (SST). (C) and (F) are from the saturated salt solution-embalmed cadaver (1 cadaver) before SST. In (A) and (D), the images are not clear enough to identify the borders of H, L, and K.

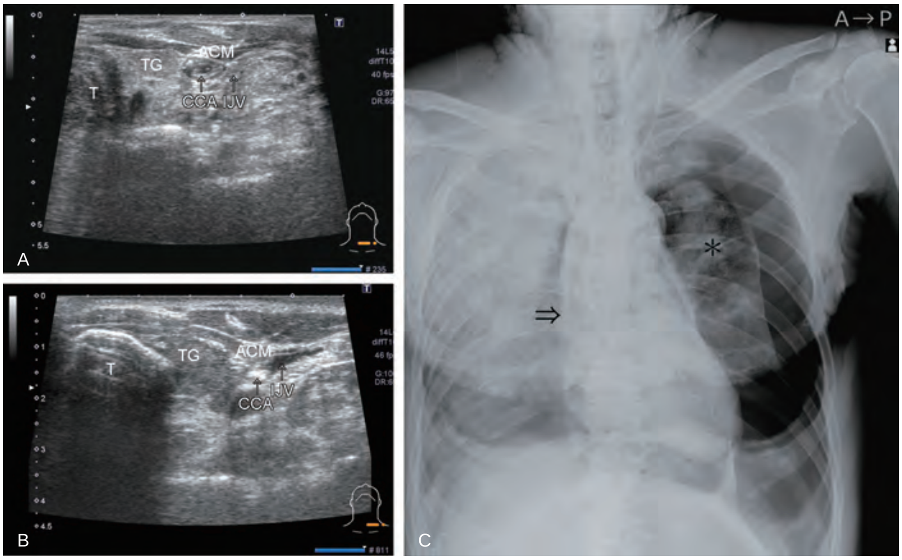

FIGURE 3. Cervical ultrasonography (A and B) and chest radiograph (C) after cervical venous catheterization of cadavers preserved by different embalming methods. (A) and (B) show transverse images through the left common carotid arteries (CCAs) and the left internal jugular veins (IJVs). (A) is from Thiel solution-embalmed cadaver (1 cadaver) before surgical skills training (SST), (B) is from the saturated salt solution (SSS)-embalmed cadaver (1 cadaver) before SST, and (C) is from the SSS-embalmed cadaver after SST. Vascular cavity of IJV shows low density in (B) but not (A). An arrowhead in (C) shows the tip of the catheter. An asterisk in (C) indicates left pneumothorax after thoracotomy. ACM = anterior cervical muscle, T = trachea, TG = thyroid gland.

for scanning intraabdominal and retroperitoneal organs in FAS-embalmed cadavers because of severe artifacts. They argued that formalin not only causes a significant swelling of soft tissues but also produces artifacts that severely impair image quality.[38] In fact, ultrasound images in FAS-embalmed cadavers were unclear (Figure 2A and D). On the contrary, the ultrasound images in both the TS and SSS-embalmed cadavers were clear (Figure 2B, C, E, and F), although fluid was observed in free spaces (pericardial, pleuroperitoneal, and peritoneal spaces) of the SSS-embalmed cadavers (Figure 2C). The reason may be that we injected approximately 25 L of SSS into each cadaver, as directed by Coleman and Kogan,[15] while the injected volume in the TS method was approximately 15 L because of its viscosity. To improve the suitability of cadavers for SST, it is planned to reduce the volume of injected solution.

Besides hardening cadavers, formalin has several other disadvantages for embalming purposes.[36] It rapidly coagulates the blood, converts tissues to a gray hue when it mixes with blood, fixes discolorations, dehydrates tissues, constricts capillaries, deteriorates with age, and has an unpleasant odor. In addition, while x-ray techniques are preferable for a quick overview of skeletal structures, fluid accumulation in the lungs, and distribution of gas content in the gut, this technique has a very limited use in FAS-embalmed

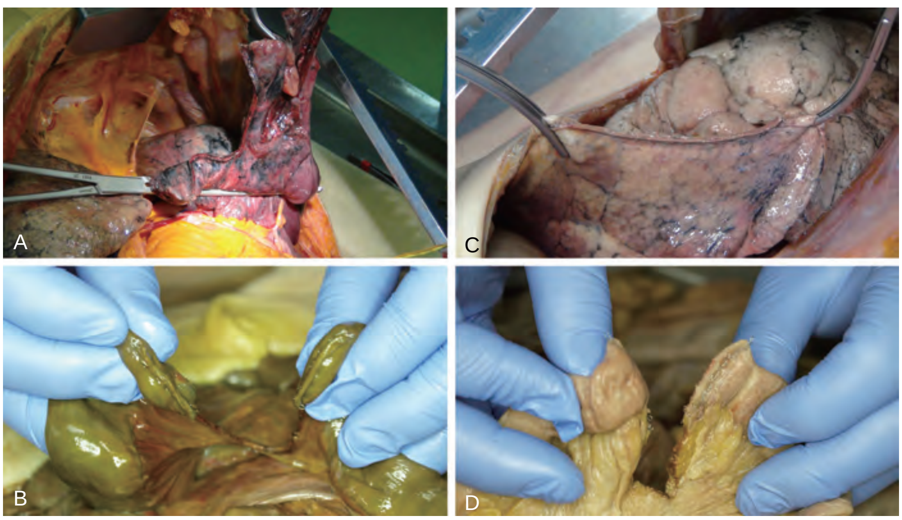

FIGURE 4. Pulmonary lobectomy (A and B) and intestinal amputation (C and D) using an autosuture-stapling device on cadavers embalmed by different procedures. (A) and (C) are from a corpse embalmed using Thiel solution (TS2). (B) and (D) are from a corpse embalmed using saturated salt solution (SSS1).

cadavers because of the poor imaging quality.[38] All these reasons indicate that FAS-embalmed cadavers are not suitable for training of central venous catheterization. On the contrary, De Crop et al[39] reported that chest radiographs of TS-embalmed cadavers with inflated lungs were of a high quality. Benkhadra et al[29] recommended TS-embalmed cadavers for ultrasound-guided punctures as a realistic and life-like model for ultrasound-guided regional anesthesia of the cervical region because the visibility of the sternocleidomastoid muscle and the needle was better and the ''pop'' feeling and nerve swelling were significantly more frequent in the TS-embalmed cadavers than in fresh cadavers. Luyet et al[40] also reported that by combining ultrasound, it was possible to simultaneously visualize the transverse processes and the lungs; however, the puncture depth was difficult to discern in many cases. Our results suggested that TS-embalmed cadavers may not be suitable enough for central venous catheterization training and SSS-embalmed cadavers might become their alternatives (Figure 3). In the present study, it was additionally confirmed that the electrosurgical knife and autosuture-stapling devices were available for both TS and SSS-embalmed cadavers (Figure 4). Recently, it was reported that TS-embalmed cadavers were used for SST of laparoscopic[27,33] and microvascular surgery.[28] SSS-embalmed cadavers may also be useful for SST for these practices.

FAS remains the most widely used preservation solution for cadavers around the world, while the TS method is not widely known. Fifty-six percent (61/109) of centers had previously heard of the TS method; however, only 11 centers (10% of respondents) used it regularly, and all of these were in Europe.[21] One of the reasons may be that the TS method is costly and involves complex components, while the SSS method is simple and involves low cost (Table 1). Moreover, TS is disposable and deactivated, while SSS is not. In conclusion, the SSS method is simple and cheap with a low risk of infection. For encouraging the diffusion and uptake of SST, many economical, technical, and hygienic difficulties still remain as unsolved issues. The SSS method will become one of the bases of the spread of SST using cadavers.

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