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RESEARCH REPORT

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The chemicals between us—First results of the cluster analyses on anatomy embalming procedures in the German-speaking countries

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Abstract

Hands-on courses utilizing preserved human tissues for educational training offer an important pathway to acquire basic anatomical knowledge. Owing to the reevaluation of formaldehyde limits by the European Commission, a joint approach was chosen by the German-speaking anatomies in Europe (Germany, Austria, Switzerland) to find commonalities among embalming protocols and infrastructure. A survey comprising 537 items was circulated to all anatomies in German-speaking Europe. Clusters were established for "ethanol"-, formaldehyde-based ("FA"), and "other" embalming procedures, depending on the chemicals considered the most relevant for each protocol. The logistical framework, volumes of chemicals, and infrastructure were found to be highly diverse between the groups and protocols. Formaldehyde quantities deployed per annum were three-fold higher in the "FA" (223 L/a) compared to the "ethanol" (71.0 L/a) group, but not for "other" (97.8 L/a), though the volumes injected per body were similar. "FA" was strongly related to table-borne air ventilation and total fixative volumes ≤1000 L. "Ethanol" was strongly related to total fixative volumes >1000 L, ceiling- and floor-borne air ventilation, and explosion-proof facilities. Air ventilation was found to be installed symmetrically in the mortuary and dissection facilities. Certain predictors exist for the interplay between the embalming used in a given infrastructure and technical measures. The here-established cluster analysis may serve as decision supportive tool when considering altering embalming protocols or establishing joint protocols between institutions, following a best practice approach to cater toward best-suited tissue characteristics for educational purposes, while simultaneously addressing future demands on exposure limits.

KEYWORDS
body donor, cadaver, conservation, embalming, fixation, formaldehyde, human tissue, occupational exposure limit the value

INTRODUCTION

Hands-on courses utilizing human tissues for educational training offer an important pathway to acquire anatomical and procedural knowledge both for undergraduate and postgraduate medical students.[1–5] Owing to the advances made in teaching technology in recent years, anatomical training can now be provided using a variety of methods, ranging from physical dissection to virtual courses visualizing structures in vivo.[6–10] Despite such developments, consensus prevails that anatomical dissection remains the gold standard for anatomical training,[11,12] while virtual facilities are seen as complementary options rather than being full substitutes.[7,8,13,14]

Anatomy training is mostly conducted on embalmed bodies or specimens.[15] The main objective of embalming procedures is to interrupt all (bio-)chemical, physical, and microbiological processes resulting in decay, autolysis, and putrefaction. A further aspect is to minimize the risk of infectivity related to the use of human specimens while providing optically and haptically acceptable tissues for training.[16,17] This infection risk can be reduced effectively by using embalmed instead of fresh specimens.[15,18]

Embalming in an anatomical context is further distinguished into fixation procedures, i.e., to establish a chemically fixed condition, and conservation procedures, i.e., to maintain the chemically fixed condition of a biological tissue.[18] Established embalming protocols mostly rely on a complex combination of organic and inorganic compounds at varying concentrations of chemicals such as formaldehyde or ethanol.[15] Nevertheless, embalming methods pose a potential health risk to anatomy staff and students working with the chemically altered tissues.[16,18–21] The most commonly used biocidal substance for embalming is formaldehyde,[22] which was classified as a group 1 carcinogen (carcinogenic to humans) by the corresponding International Agency for Research on Cancer (IARC) in 2004. Strict occupational exposure limits (OELs) of 0.37 mg/m^3 (0.3 ppm) have been established to protect against adverse health effects resulting from formaldehyde exposure, following a trend to further decrease OEL.[23] To ensure workplace safety is adhered to in facilities in which anatomical dissection work is performed, it was necessary to mandate the use of the equipment to comply with the OELs.[24] In 2015, following the proposal of Jens Waschke (Munich, Germany), the Anatomische Gesellschaft (German Anatomical Society) established a working group for the “Reduction of Workplace Formaldehyde Exposure” to establish potential measures in formaldehyde reduction in compliance with the OEL regulations. Depending on the specific embalming protocol deployed, these measures include air ventilation systems, temperature control, and reduced formaldehyde quantities used in the protocol. Some institutions chose to partially or fully substitute formaldehyde using alternative protocols, i.e., with ethanol or saline-based embalming methods.[4,18,25] However, the success of formaldehyde reduction is complex and depends on a variety of factors.[5,24] In consequence, effective measures for lowering formaldehyde or other chemical exposure used by some institutions rendering effective are of interest to the broader community of anatomists.

Contemporary embalming protocols are not only used based on departmental history and evolution over time, but also on the limitations given by the facility infrastructure, working experience, the legal framework and, potentially influence the criteria under which bodies are accepted post-mortem.[14] The variety of protocols is manifold, resulting in a multitude of different compositions of embalming chemicals.[14,15]

The reevaluation of formalin use in the European restriction roadmap period 2025–2027[26] likely result in further reductions of formaldehyde OELs. Potentially the requirement will arise to certify embalming protocols according to official regulations. To effectively fulfill this purpose, a collaborative approach seems attractive but warrants baseline data. To enable such an approach, it is important to find commonalities over the entire process of embalming and to evaluate possibilities of modifying the processes to suit all participating institutes.

A previously conducted survey laid the basis for this study.[14] This survey included information from a large number of anatomy departments in German-speaking parts of the European DACH region (Germany (D), Austria (A), Switzerland (CH)). This given study aimed at obtaining additional information in a structured survey, allowing us to assess which dependencies exist between the main categories of body donation, infrastructure, embalming protocol, and tissue use. Such combined information is relevant to assess if a certain protocol could potentially be used in another anatomy environment, if certain requirements on the building and safety are met.

It was hypothesized that key infrastructural features such as specific air ventilation systems, room temperature, or explosion-proof installations strongly relate to the embalming protocol used.

MATERIALS AND METHODS

Survey conceptualization and distribution

A survey was designed to include a majority of procedures and methods related to the anatomical embalming of human corpses (herein-named bodies). The survey was based on iterative feedback provided by the members of the "Working Group on the Reduction of Formaldehyde Exposure" of the Anatomische Gesellschaft (German Anatomical Society). Organizational, (infra-)structural, and staff-related items were included. All anatomy departments based in the German-speaking regions were approached in Austria, Germany, and Switzerland.

A pilot version of the survey was circulated to four anatomy departments volunteering for an initial trial, namely institutes in Berlin, Dresden, Kiel, and Munich (all in Germany). Further refinements of the survey were made, based on feedback received by these departments before a final version of the survey was sent to all German-speaking anatomy departments via the Anatomische Gesellschaft. This final version of the survey covered the four major topics divided into four major sections across 36 pages and 537 items outlined below:

- Procedures prior to the arrival of the body at the mortuary: measures taken at the place of death, transportation, storage, delivery to the anatomy mortuary
- Procedures following the arrival of the body at the mortuary: infrastructure including chemicals and tissue storage, disposal, dissection tables, and ventilation, safety measures, preparation of fixatives, embalming protocol, technical equipment, tables
- Procedures upon completion of embalming: tissue storage, chemicals, and equipment needed for maintenance, measures for the preservation
- Procedures following tissue use: duration of bodies (i.e., period of use), potentially hazardous chemicals, mode, and site of the burial of the dissected bodies and tissues

Survey feedback and processing

The response rate for the prototype survey was 100% (4/4), and the response rate for the final version was 58% (29/50). Seven anatomy departments have been identified as having no active body donation system at the stage of the survey. Fourteen departments declined to provide feedback or did not respond to the survey and follow the reminders. The flow chart presented in Figure 1 summarizes the timing and measures of inclusion.

Statistical evaluation

The data were analyzed using Prism version 9 (GraphPad Software Inc., La Jolla, CA, USA), SPSS version 28 (IBM, Armonk, VA, USA), and Microsoft Excel version 16.49 (Microsoft Corp., Armonk, NY, USA). Normal distribution was assessed using the D'Agostino and Pearson test.[27] A Kruskal–Wallis test with post hoc correction (Dunn's test) was used for between-group comparison of ethanol, FA based, or "other" embalming. Fisher's exact test and/or Cramér V (φ) correlations were determined to compare categorial items between embalming types. φ values of 0.1–0.3, >0.3–0.5, and >0.5 were considered small, medium, and large effect sizes.[28] p values ≤ 0.05 were considered statistically significant. Values adding up to more than 100% are the result of rounding.

RESULTS

Data were processed based on the feedback provided by the 29 human anatomy departments (Figure 2). The seven departments which reported to have no active body donation system described that they predominantly received bodies from other institutions for their purposes. Five had their own donation system underway at the time of the survey (no data shown). Based on the resulting data, a basic manual clustering was conducted, resulting in three general modes of embalming, namely "ethanol-based", formaldehyde ("FA") based, and "other". The latter included, e.g., Thiel embalming, Jores and Basler and Weigner solutions.[15,25,29–34] The statistical analyses below are based on this three-item cluster.

Logistical framework of the embalming and general safety measures

The post-mortem interval before the bodies were received at the institutes (i.e., time before pickup) averaged 72 h (minimum 6 h, maximum time indefinite). The bodies were transported in a cooled condition in 51.7% and uncooled in 41.4% (6.9% unspecified). Transportation time averaged 5 h (minimum 1 h, maximum 48 h). Mortuary business hours on working days only were reported in 69.0% and a 24/7 in 24.1% of responses (6.9% no response). Specimen use for teaching and research was specified by 27 respondents (93.1%), for teaching only by one respondent (3.5%; 3.5% no response).

The average injection volume per body was 23 L (median 20 L, minimum 8 L, maximum 70 L). Ethanol was considered an essential component of the embalming in 51.7% of all responses. No significant difference was observed between embalming categories (Figure 3).

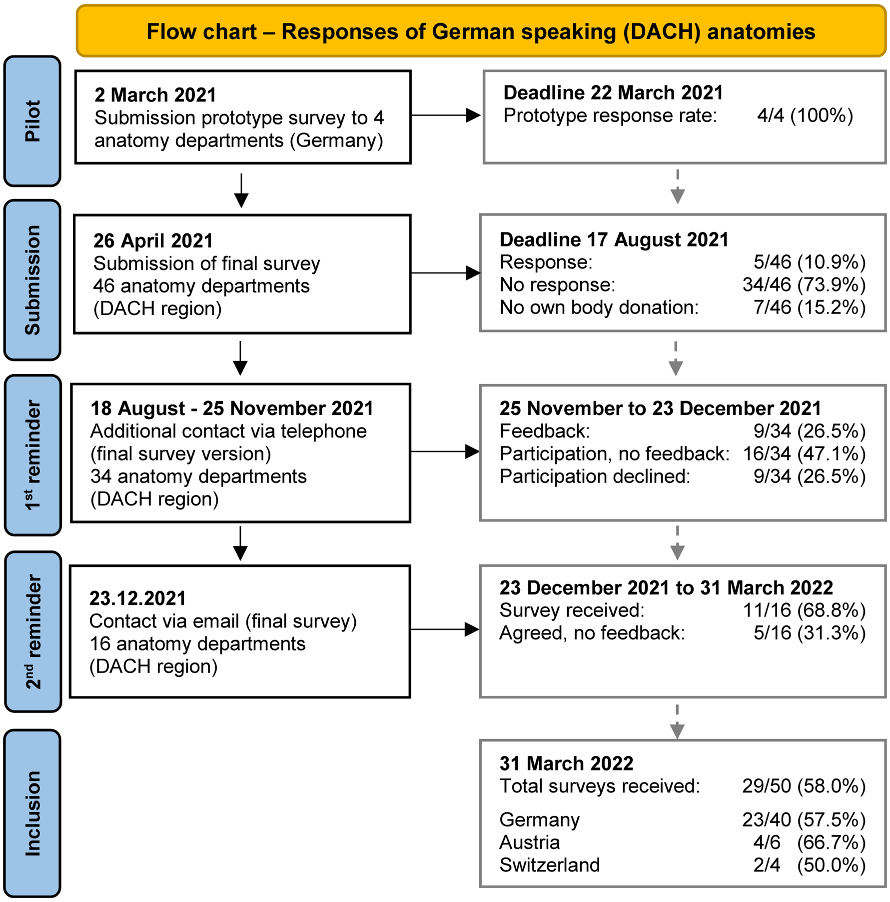

FIGURE 1 Flow chart summarizing the response rates from German-speaking anatomies between March 2, 2021 and March 31, 2022. Total survey response included those human anatomy departments with an active body donation system only. Veterinary anatomy departments are not listed. Figures may add up to more than 100% as a consequence of rounding.

No significant difference was observed for the volumes of formaldehyde (37% by volume) injected at the time of fixation between the techniques, with averages of 1.1 L (median 1.0 L), 1.6 L (median 1.5 L), and 1.5 L (median 1.4 L) for "ethanol", "FA", and "others", respectively. The total quantity of formaldehyde (37%) used averaged 135.0 L/a (median 98 L/a). Significantly higher volumes of formaldehyde (37% by volume) were used with the "FA" technique (mean 222.6 L/a; median 121 L/a) when compared to "ethanol" (mean 71.0 L/a; median 70.0 L/a; $p=0.03$). No significant difference was observed between "FA" or "ethanol" and "other" (mean 97.8 L/a; median 98.0 L/a). On a global average, 1.8 L (median 1.4 L) of 37% formaldehyde was used per body and year irrespective of the type of embalming, including all processes related to anatomical fixation and conservation.

Institutes using "ethanol" or "FA" embalming had business hours limited to working days predominantly, whereas "other" embalming types were associated with 24/7 contact times ($\varphi=0.475$; $p=0.008$). Likely totaled the annual use of formaldehyde 100 L if the total volume of the injective exceeded 1000 L/a per institute. Vice versa, if 1000 L/a or less were used as the total volume, the total quantity of formaldehyde exceeded 100 L/a ($\varphi=0.529$, $p=0.025$). Departments utilizing >20 bodies/course simultaneously were more likely to use over proportionally large injection volumes >1000 L/a ($\varphi=0.405$, $p=0.035$).

Ethanol was highly likely involved as a primary component in the case of "ethanol" embalming, whereas it was occasionally used as an additive or supplement of the formula in "FA" embalming or "other" ($\varphi=0.872$, $p<0.001$). If the total volume of injective exceeded 1000 L/a, ethanol was more likely to be used as the main component of the embalming ($\varphi=0.520$, $p=0.023$). Explosion-proof installations were associated with "ethanol" and "other" as the basic formula ($\varphi=0.412$, $p=0.029$). Explosion-proof facilities in the mortuary were unlikely to exist in the case of "FA" embalming ($\varphi=0.412$, $p=0.029$) or if the air exchange rate was >10×/h in the dissection laboratory ($\varphi=0.410$, $p=0.040$). However, in at least 13.3% of the facilities using ethanol-based protocols or ethanol as a main component of the embalming, explosion-proof installations have been described as not to exist.

Smaller injection volumes (≤20 L) were associated with a total number of bodies of 20 or less in the dissection laboratory ($\varphi=0.497$, $p=0.004$). Injection volumes ≤20 L/body were related to smaller student cohorts (≤200) in the dissection laboratory, larger volumes (>20 L/body) were seen more often in larger cohorts ($\varphi=0.412$, $p=0.031$). Moreover, large quantities of injective were related to student numbers per table of 8 or more ($\varphi=0.439$, $p=0.018$).

The use of face protection for the injection step of the embalming was linked to injection times of 8 h or longer ($\varphi=0.494$, $p=0.027$).

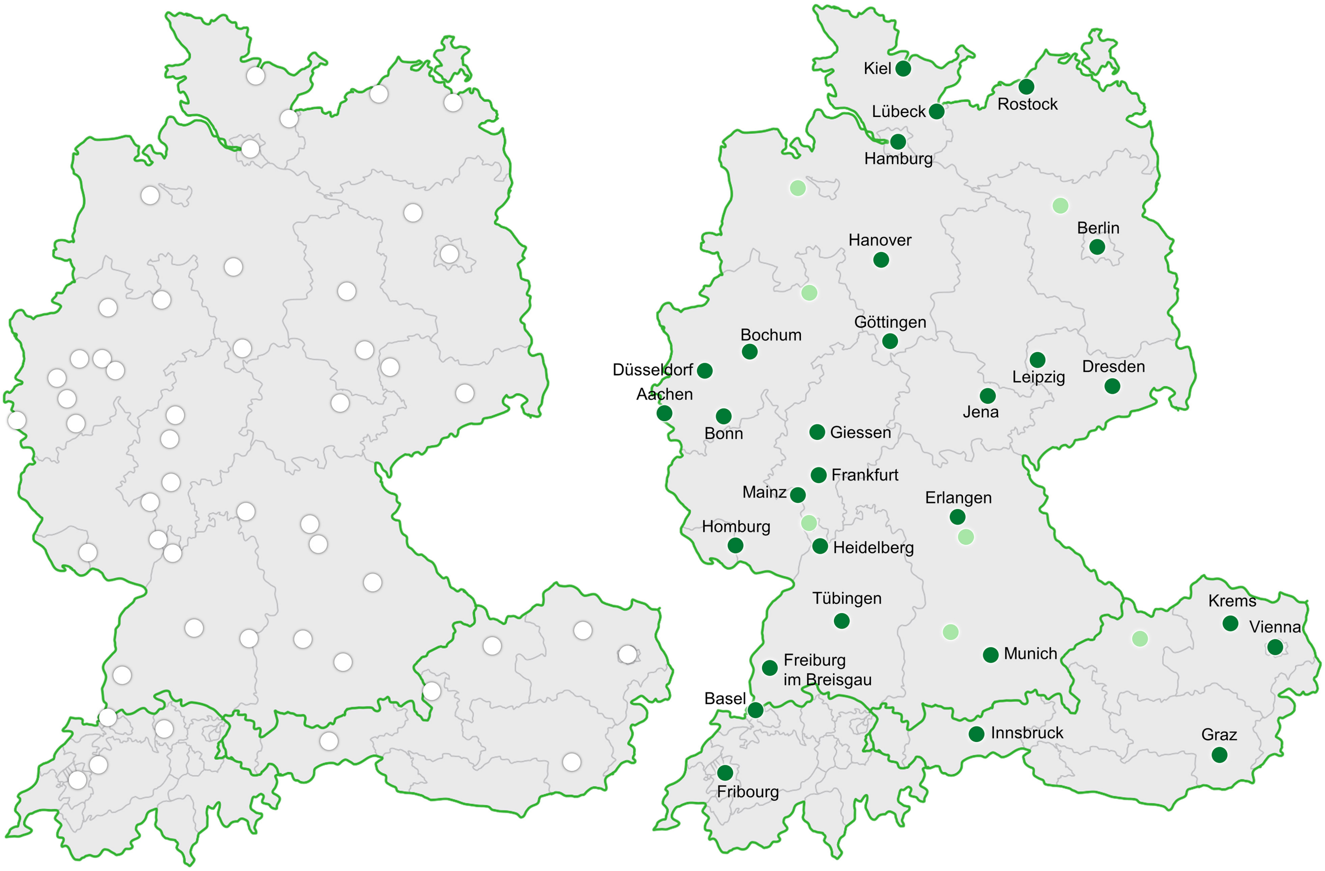

FIGURE 2 Graphical summary of all anatomy departments contacted in the German-speaking regions of Austria, Germany, and Switzerland (white circles and left side). Response to participate was received from 29 of the 50 human anatomy departments, providing detailed protocols (right side). Veterinary anatomy departments are not shown. Dark green circles indicate anatomy departments providing completed surveys, and light green those with no (active) body donation system at the time of the survey.

Shorter injection times (≤4 h) were associated with mortuary air ventilation systems installed at the ceiling and floor; table-borne air ventilation systems were more common for longer injection times (>4 h; $\varphi=0.566$, $p=0.005$). The option for cooled transportation was closely related to temporary body storage ($\varphi=0.381$, $p=0.029$) and mortuaries comprising more than one room ($\varphi=0.407$, $p=0.012$).

Technical features of the mortuary

The room temperature of the mortuary averaged 20°C (minimum 16°C, maximum 22°C) (Figure 4). The mortuary consisted of one room only in 37.9% of cases and more than one room in 51.7% of cases (ca. 10.3% not reported). The average space volume of the mortuary was 308 m^3 (median 276 m^3, minimum 51 m^3, maximum 848 m^3). Explosion-proof facilities were found in 48.3% of cases (34.5% no explosion-proof facilities, 17.2% not reported). Air ventilation systems have been reported to exist in 86.2%, and none in 6.9% of cases (6.9% not reported). The types of air ventilation systems in the mortuary are given in Table 1.

The injection time averaged 20 h (minimum 1 h, maximum 96 h). Personal safety equipment has been reported to be used in 96.6% of responses, however, to varying extent (Table 2). As an example, gloves were reported not to be used in 3.5%, and their use has not been specified in 20.7% of cases (3.5% data not given). Further, it could be observed that mortuaries with a reachability on working days only predominantly used Nitrile or Latex gloves ($\varphi=0.479$, $p=0.014$).

Several observations were made in the context of the number of rooms linked to the mortuary installation. If the mortuary consisted of more than one room, delivery intervals were shorter (<2 h; $\varphi=0.417$, $p=0.027$). Further, if the space volume was ≤150 m^3, more likely respiratory protection was worn than none when injecting the body ($\varphi=0.422$, $p=0.024$). Concerning the features of the air ventilation systems found in the mortuary, table-borne installations were related to air exchange rates of ≥10×/h in the dissection laboratory, as well as ceiling or floor ventilation installations in case of >10×/h in the dissection laboratory ($\varphi=0.560$, $p=0.025$).

Technical features of the dissection laboratory

The space volume of the dissection laboratory averaged 1992 m^3 (minimum 154 m^3, maximum 8000 m^3; Figure 5); it was not reported

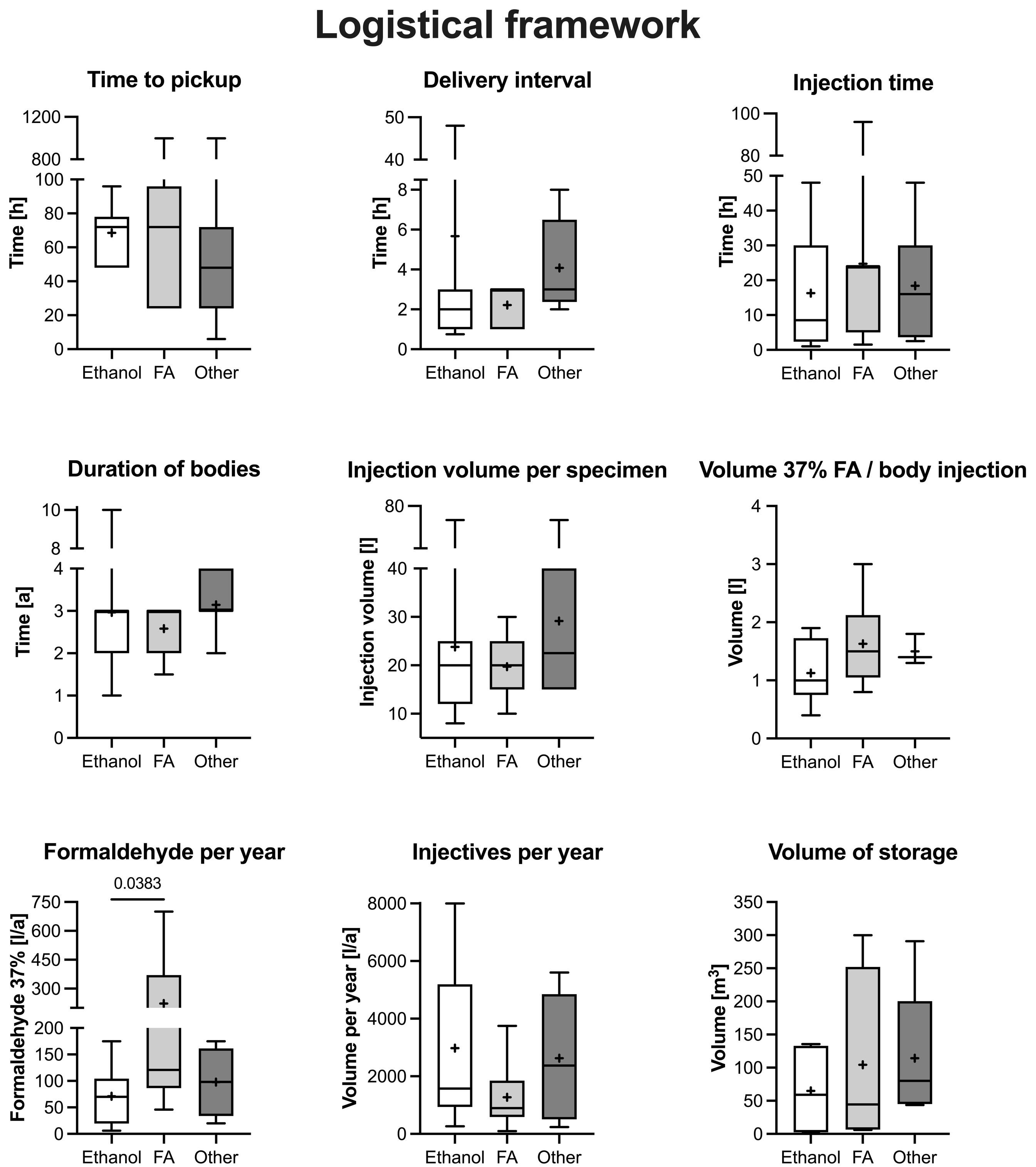

FIGURE 3 Box plots comparing different information on the logistical framework separated for "ethanol", formaldehyde ("FA") based, and "other" embalming techniques. The boxes show the 25th, 50th, and 75th percentile, whiskers the minima and maxima. The solid line marks the median, and "+" indicates mean values. A broad spread and no significant differences were observed for each of these items. Times to pick up the bodies, delivery interval, and injection time varied broadly. The duration time of the bodies was similar for all techniques. The predominant use of "ethanol" was related to the largest volume consumption per body and the largest quantities of fixative per annum. Formaldehyde use per year and storage volume were the largest for "FA" techniques.

by 24.1% of the respondents. Dissection room temperature averaged 19.0°C (minimum 14°C, maximum 22°C). 82.8% of the institutes possessed an air ventilation system in their dissection laboratories, and 3.5% had none (13.8% not reported). Air ventilation in the dissection laboratory comprised of the table- (51.7%), ceiling- (17.2%), side wall- (3.5%), floor- (10.3%) borne installations, with the most

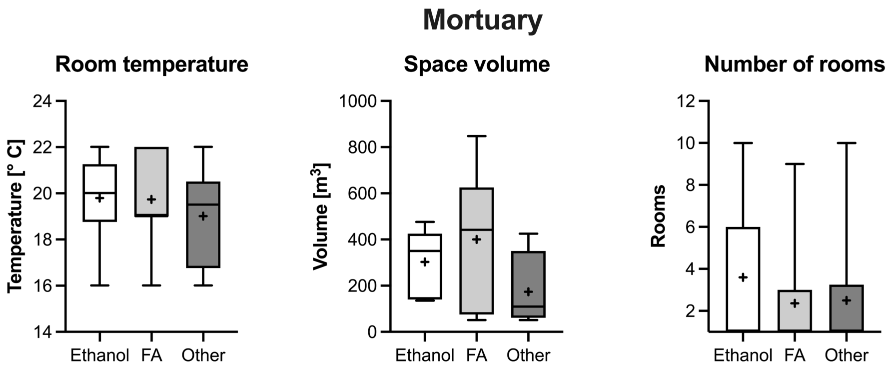

FIGURE 4 Box plots comparing the different technical configurations of the mortuary, separated for "ethanol", "formaldehyde" (FA) based, and "other" embalming techniques. The boxes show the 25th, 50th, and 75th percentile, whiskers the minima and maxima. The solid line marks the median, and "+" indicates mean values. Room temperature, space volume, and number of rooms were similar for all techniques.

TABLE 1 Different types of air ventilation systems are used in 86.2% of mortuaries, while not being present in 6.9% (data not given 6.9%).

Table	Ceiling	Sidewall	Floor	Unspecified
37.9%	20.7%	10.3%	13.8%	3.5%

Note: In case of more than one system type, the most powerful system is given (table > ceiling > sidewall > floor > unspecified).

powerful system installed mentioned in this report (table > ceiling > sidewall > floor > unspecified air ventilation). In the 13 responses on air exchange rates with existing air ventilation systems, an average of 14.0×/h was reported (minimum 6×/h, maximum 32×/h). No significant difference was observed between the use of "ethanol", "FA-based", and "other" embalming methods.

The average number, of course, attendees simultaneously present was 200 (median 157, minimum 60, maximum 520) students, with an average of 9 (median 9, minimum 4, maximum 15) students per body, independent of the embalming techniques used (Figure 6).

A link between lower temperature in the dissection lab (≤18°C) and lower numbers of bodies (≤20 bodies) was found ($\varphi=0.480$, $p=0.043$). Moreover temperatures ≤18°C were linked to table-borne air ventilation systems, and >18°C made it more likely that ceiling-borne air ventilation was used ($\varphi=0.569$, $p=0.041$). The larger space volume of the dissection laboratory (>2000 m^3) was negatively related to the existence of explosion-proof facilities in the mortuary ($\varphi=0.540$, $p=0.030$).

The configuration of the air ventilation system in the dissection laboratory likely resembled the configuration of the mortuary ($\varphi=0.674$, $p<0.001$). Smaller space volumes of the dissection laboratory (≤2000 m^3) were linked to smaller space volume of the mortuary (≤150 m^3; $\varphi=0.565$, $p=0.006$) and body storage space (≤100 m^3; $\varphi=0.506$, $p=0.047$). Table-borne air ventilation systems were linked to "FA" embalming and table-, floor-, or ceiling-based systems to "ethanol" embalming (mortuary: $\varphi=0.497$, $p=0.045$; dissection room: $\varphi=0.658$, $p=0.003$). No clear trend was observed for "others".

Shorter injection times (≤4 h) were associated with mortuary air ventilation systems situated at the ceiling and floor, whereas table ventilation was more common for longer injection times (>4 h, $\varphi=0.566$, $p=0.005$).

Higher air exchange rates (>10×/h) were seen if the duration of the injection time was ≤4 h ($\varphi=0.485$, $p=0.034$). If the injection time exceeded 4 h, air exchange rates were likely ≤10×/h ($\varphi=0.485$, $p=0.034$). Small (≤1000 m^3) to moderate (1001–2000 m^3) dissection laboratory space volumes were associated with higher air exchange rates (>10×/h), and larger space volumes (>2000 m^3) to lower air exchange rates (≤10/h; $\varphi=0.505$, $p=0.037$). Moreover, the application of formaldehyde-based embalming was moreover linked to lower air exchange rates (≤10×/h; $\varphi=0.437$, $p=0.018$).

A proposed cluster to visualize connections between infrastructure, logistical framework, and the embalming chemicals.

Based on the here obtained data, a manual cluster was designed to summarize the findings and the statistical association between the different items. It is presented in Figure 7.

DISCUSSION

A fingerprint on chemical composition and related infrastructure for embalming procedures

The main goal of this study was to determine commonalities among embalming procedures performed post-mortem by anatomy departments in German-speaking (DACH) countries. The chemical protocols being used, the infrastructure, and the logistic framework alongside measures for workplace safety were considered[35,36] using a questionnaire comprising 537 items. Twenty-nine of the 50 human anatomy institutes in German-speaking countries (including Switzerland) operating at the time of the survey provided detailed information on their setup. Seven institutes received their bodies from other institutions or had no donation program in place. Thus, 67.4% (29/43) of institutes with active body donation systems provided content feedback. The main influential factors were identified manually and

TABLE 2 Personal safety equipment used by the mortuary staff.

Personal safety equipment	Face protection	Respiratory protection	Safety clothing	Safety shoes	Gloves
Yes	82.8%	79.3%	89.7%	93.1%	93.1%
No	10.3%	13.8%	6.9%	3.5%	3.5%
Not given	6.9%	6.9%	3.5%	3.5%	3.5%

Note: Face protection includes face masks, shields, and glasses, while respiratory protection entails devices to prevent smoke or chemical substance inhalation.

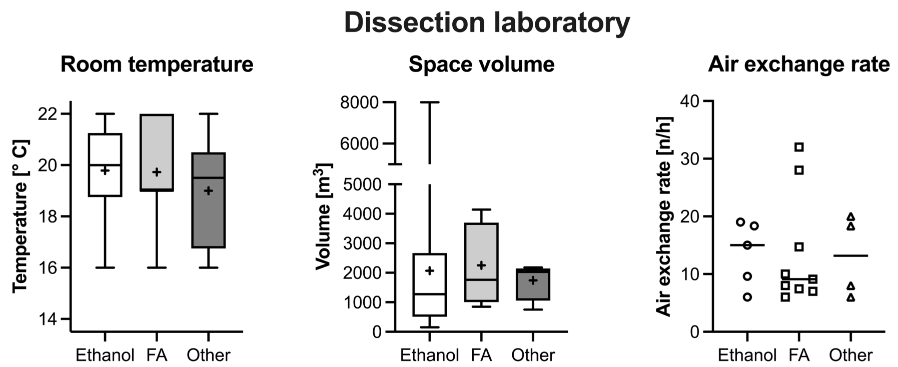

FIGURE 5 Plots comparing the different technical configurations of the dissection laboratory, separated for "ethanol", formaldehyde (FA) based, and "other" embalming techniques. The boxes show the 25th, 50th, and 75th percentile, whiskers the minima and maxima. The solid line marks the median, and "+" indicates mean values. Room temperature, space volume, and air exchange rates yielded no significant difference between the techniques applied.

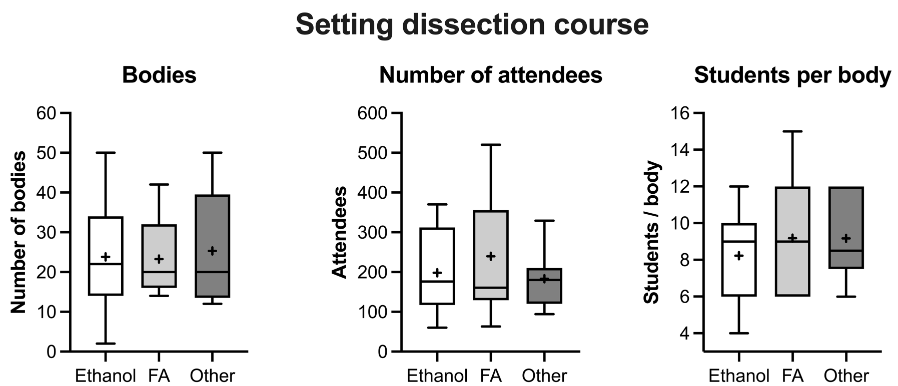

FIGURE 6 Box plots comparing the different teaching conditions in the dissection laboratory, separated for "ethanol", formaldehyde ("FA") based, and "other" embalming techniques. The boxes show the 25th, 50th, and 75th percentile, whiskers the minima and maxima. The solid line marks the median, and "+" indicates mean values. A larger spread of bodies used for the dissection lab was seen in "ethanol", and a trend toward higher attendee numbers as well as students per body using "FA".

clusters determined and further analyses were conducted based on chi-square, Cramér V, and subsequent Fisher's exact tests.[37,38] For this purpose, the existing protocols were allocated to the "ethanol", "FA", and "other" groups, based on the premise that main fixatives form the key elements anatomists consider in their embalming protocols.[27] The resulting manual cluster is outlined in Figure 7.

The composition of the embalming chemicals differed broadly between the centers, alongside the infrastructural and logistic framework under which the embalming takes place. This diversity is manifold in German-speaking Europe, as outlined previously by Waschke et al.[14] The diversity is likely the consequence of long-established protocols with tissue properties both staff and students got accommodated to. It is to the effect that even new institutional buildings or extensive renovation measures would not necessarily result in different embalming protocols.

Vice versa, staff mobility between institutions may have resulted in alternative protocols deployed in anatomy departments that used other embalming types exclusively. This was the case in Graz, previously a center of exclusive Thiel embalming, where ethanol-glycerin embalming has meanwhile been introduced[39] (own unpublished results). Further, complexity is added if more than one technique is used at the same time, e.g., to cater toward undergraduate and postgraduate courses with different demands on the embalmed tissues. Given the legal framework on formaldehyde OELs,[26] it is likely that

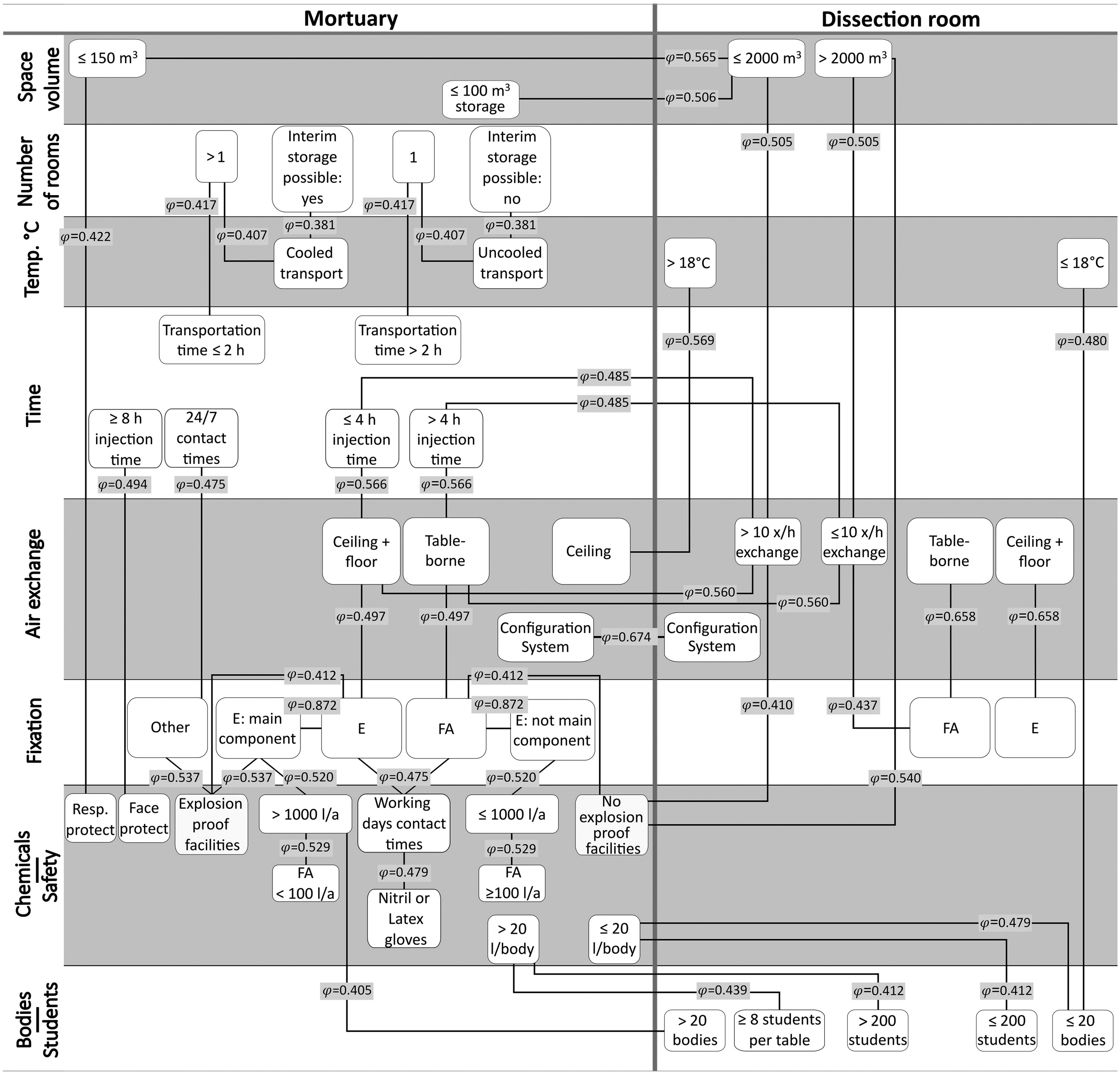

FIGURE 7 Summary of findings by manual clustering methods. Connections between the items represent the statistical likelihood ratio (ϕ) according to Cramér V analysis while being significant at levels of $p \leq 0.05$ in Fisher's exact test. This cluster may be useful, to begin with the item yielding the highest priority, then assess further connections to the given protocol. E, ethanol; FA, formaldehyde; ceiling/floor/table, location of the air exchange system; contact times, reachability of the department; injection time, duration of injection of fixation solution into the body.

in the future a trend will be seen toward using similar embalming protocols more broadly, depending on the requirements on tissue properties, (future) building installations such as air ventilation systems and exchange rates, explosion protection, and likely the need to license embalming protocols under the European legislation on the use of biocidal substances.

Identifying the most suitable embalming method in the future in organized trials could be one of the recommendations made from the given results of this cluster analysis. Such trials should entail a critical evaluation of the feasibility of specific embalming types in multi-center analyses. Thereby, bodies and protocols could be exchanged within the legal and ethical framework for best practice to assess both the resulting tissue features and if safety measures can be achieved.

Of interest, none of the anatomies surveyed from the DACH region responded that they would use chemical measures to lower an (existing) high formaldehyde exposure, e.g., using InfuTrace™ (American Bio-Safety, Rocklin, CA, USA)[5,40] or monoethanolamine.[41] The specific reason for this lack of use remains obscure. It may be related to the cost of these chemicals, or this measure being less effective in light of abundant other options to achieve the desired formaldehyde levels.

The embalming protocol appears to be an unspecific indicator for the air ventilation system being used

One of the initial assumptions was that the type of embalming would allow for conclusions on the specific type of air ventilation system being used, specifically to meet the OELs requirement of 0.3 ppm for formaldehyde or 200 ppm for ethanol.[42] It was shown that "ethanol" protocols were most likely related to ceiling- and floor-borne ventilation systems, whereas "FA" was most likely related to table-borne ventilation installments and exchange rates of ≤10×/h. Though there was a strong Cramér V correlation found for both clusters in the mortuary and the dissection room environment, this correlation was never found to be perfect, i.e., deviations exist to a certain extent. The findings on "FA" are in line with recommendations on the effective removal found elsewhere,[43] and therefore aid in keeping the OELs below 0.25 to 0.55 ppm, meeting the ceiling values for short-term exposure of 0.60 ppm.[44] Moreover, the users of "ethanol" protocols reported more often that their air exchange rate either exceeded 10×/h or that it was completely unknown. This finding may be explained either by old installations without calibration, lacking awareness on the importance of the air ventilation system, or most likely due to the high level of specialization of the air equipment maintenance, making it difficult for the end user in anatomy to ascertain these specific values. No dependence on air ventilation systems was found for "others", which is likely due to the inhomogeneity within this group and the low overall number.

Moreover, it was found that air ventilation systems were used symmetrically in both the mortuary and the dissection laboratory concerning the installation site. A symmetric use may appear reasonable to a certain extent both from a procurement and maintenance perspective, but, not from the perspective of both workplace safety and operation economy. As an example, laminar flows comprising ceiling-borne inflows and table-borne extractions operating at high air exchange rates, often beyond 20×/h, are known to be effective to reduce peak exposure in the mortuary where chemicals are used undiluted or at high concentrations.[5,24] At the same time, one or two operators working simultaneously on the bodies in the mortuary cause minute thermal turbulence in the laminar flow. Within the dissection laboratory environment, however, the laminar flow setting may not be as effective to fulfill the same purpose for fluid mechanics considerations. Here, the chemicals will be diluted in the tissues, and exposure to chemicals will mostly be related to the tissue the students are operating on, not on handling the chemicals themselves. Hence, a large number of participants in the dissection laboratory being thermal sources introduces significant turbulence, thereby disrupting the laminar flow, with a detrimental effect on the effectiveness of the air ventilation.[24] These effects can technically only partly be compensated for by further increasing the airflow. In line with this, laminar flows have been reported to deteriorate air comfort, and the drying effects on the tissues as a consequence of higher air flow rates increase the need of maintaining the tissues in a well-preserved state (personal communication, Erlangen). A last aspect to consider here is the operating economy, both from an ecological and fiscal perspective. Air nozzles or ventilation slits[5,24] may offer advantages here. In consequence, an asymmetric installation of air ventilation systems in the mortuary and dissection laboratory should be critically considered to address the needs of chemical exposure, working comfort, tissue preservation, and operating economy. Air ventilation systems based on the principle of impulse technology may here offer an alternative.

The "ethanol" group presents a unique difference when compared to the "FA" group

The key characteristics of the "ethanol" and "FA" group are summarized in Figure 8. The "ethanol" group is strongly linked to ceiling- and floor-borne air ventilation systems in both the mortuary and the dissection laboratory. Moreover, it could be shown that "ethanol" is linked to larger total quantities of injective and explosion-proof facilities. The cluster related to the "ethanol" group was indirectly linked to lower quantities of formaldehyde (<100 L/a), and indirectly to the simultaneous use of >20 bodies for dissection purposes. Compared to the "ethanol" group, the "FA" group showed a unique difference

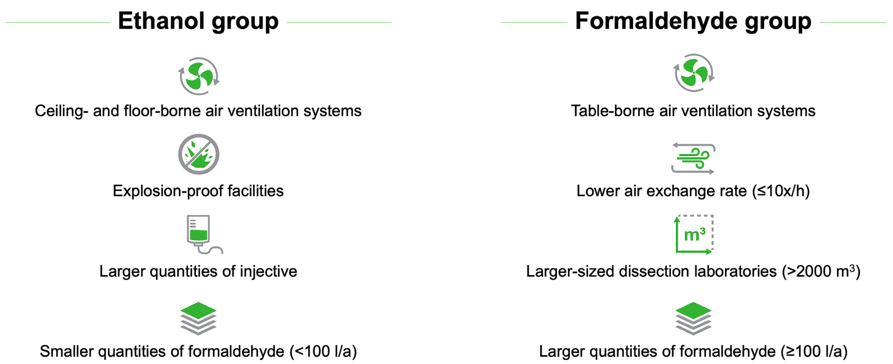

FIGURE 8 Main characteristics derived from the groups using primarily ethanol or formaldehyde as their primary embalming agent.

and is characterized by table-borne air ventilation, air exchange rates ≤10×/h, and indirectly linked to larger dissection laboratories (>2000 m^3) as well as indirectly to higher quantities of formaldehyde (>100 L/a). Surprisingly, in spite of larger absolute quantities of formaldehyde used per annum by the "FA" group, no difference was observed compared to the "ethanol" group regarding formaldehyde quantities during injection. In line with other findings from the cluster in Figure 7, a majority of the formaldehyde use in excess in the "FA" group may be related to procedures secondary to the injection, e.g., the submersion step of fixation, tissue maintenance, and conservation.

Explosion-proof installations seem reasonable especially if flammable vapors may arise from the chemicals deployed,[45] or if the specimen themselves may pose a risk of combustion especially directly following the embalming procedure.[46] Surprisingly, not all institutes deploying ethanol as a main component of their embalming protocol responded to have explosion-proof mortuary facilities, which may pose a certain risk if explosive vapors start forming.[45] It has been stated in literature that the critical concentration of ethanol is reached at 3.5% of fumes.[45] Similar considerations should be made if phenol forms part of the embalming formula.[46] Critical concentrations are unlikely to be reached in the dissection laboratory environment, especially if air ventilation systems have been installed,[36,47] and if room temperatures are lowered as to decrease permissible concentrations below the critical limit.[48] However, especially in the mortuary environment, where undiluted chemicals are handled at large quantities within relatively low space volumes and limited air exchange but higher room temperature, a realistic scenario of an accident exists.[48] Such unfavorable constellations exist in certain environments, e.g., at the Medical University of Graz, which lead to a broad number of necessary infrastructural upgrades to meet the requirements for handling ethanol and other explosives for ethanol-glycerin,[18] modified Thiel[34] and also for other types of embalming. Lower room temperature also helps to decrease the effective concentrations of formaldehyde irrespective of the protocol being used.[5,49] Our hypothesis, therefore, is that key infrastructural features such as specific air ventilation systems, room temperature, or explosion-proof installations have a strong impact on the embalming protocol.

A complex interaction is observed for operating procedures to achieve best practice

A number of interactions have been found which at first instance have not been directly related. As an example, those mortuaries with contact times on working days more often used nitrile instead of latex gloves more commonly. At the same time, anatomy institutes receiving bodies on working days only more frequently used "ethanol" or "FA" protocols. The protocol of "others" was related to permanent opening times for body reception. Though it is unlikely that even for the latter case bodies are embalmed at night time, a reception 24/7 facilitates the bodies being kept in a cooled and accessible environment for the anatomy staff, while at the same time lowering the expenses related to storing the bodies in public or funeral home facilities. Nitrile gloves have been shown to offer certain advantages over latex explaining for their predominant use.[50] They provide better chemical stability.[51] However, at the cost of their mechanical properties,[52] recommended usage time,[53] and the level of dexterity offered.[54] Combining these three observations one may find that the "other" protocols such as Jores,[30] Weigner,[25] and Thiel[33,34] embalming may be more delicate to produce suitable results.

Limitations

In spite of the considerable high feedback rate provided by the DACH anatomy institutes, it is impossible at this stage to determine the impact of missing data from those anatomies which did not provide their information. The large number of survey items may have affected the feedback rate negatively; however, this level of detail was needed to achieve the data density required for this given assessments and future studies. While the study presented here primarily focused on a comparison based on chemically different embalming agents, other factors might be more relevant to achieve cluster protocols. This aspect will be part of future studies on the topic.

CONCLUSIONS

Though certain predictors appear to exist for the type of embalming used, infrastructure, and technical measures, the broad variation in embalming protocols and technical setup makes it impossible to deduce specific recommendations. Key factors limiting the choice of embalming types remain the explosion-proof setup, the type of air ventilation system installed, space volume, and temperature, and most importantly user preference to best cater toward research and education needs. Future computational analyses may help identify more complex interactions between the various parameters of the survey, thereby providing more detailed recommendations on the embalming type most suited.

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