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ORIGINAL ARTICLE

Implementation of modern tools in autopsy practice—the way towards contemporary postmortal diagnostics

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Abstract

Medical, legal, and socioeconomic issues have contributed to the decline of autopsy rates. Pathology-related factors, however, with changing clinical duties on the one hand and decreasing interest and lack of substantial technical developments in this field on the other, may have contributed to this condition as well. We present our experience of a restructuring project that culminated in the introduction of a modernized postmortal diagnostic (PMD) unit: Workflows of PMD procedures and space organization were restructured according to LEAN management principles method. Classical autopsy suites were transformed into postmortal operating rooms. A PMD pathologist staff was designated to perform postmortal operative diagnostics (i.e., using laparotomy and thoracotomy approaches) with the intention of gradually replacing classical autopsy procedures. Postmortal minimal invasive diagnostics (PMID) using laparoscopy and thoracoscopy were successfully implemented with the expertise of clinical colleagues. Reorganization of workflow reduced turn-around times for PMD reports from a median of 33 days to 15 days. Short-term analysis revealed that this combined effort leads to a slight increase in the number of adult postmortal examinations 1 year after the introduction of this project. A change of culture in postmortal diagnostics may contribute to a better reputation of postmortal examinations from the perspective of clinicians, the general public, and affected relatives of the deceased. It may also serve to demonstrate that the pathology community is keen not only to preserve but also to further develop this valuable tool for medical quality control and education.

Keywords Autopsy · Postmortal diagnostics · Minimally invasive · LEAN management

Introduction

Although the value of autopsies has clearly been shown, the worldwide decrease in autopsy rates is a fact. This decline poses a serious problem as regards quality assurance of medical treatment, medical knowledge in general, and education in particular [1–3]. Similar to many academic pathology institutions in Europe [3–7], we, at the Institute of Pathology of the University of Bern, Switzerland, have also experienced a dramatic decrease in autopsy numbers during the past 20 years. Many reasons have led to the current situation, including a changing perception of the autopsy in medicine and in the public eye, legal factors, and medico-economic pressure [2]. In addition, the last decades have shown that the field of pathology is changing, accelerated by personalized healthcare, digitation, and molecular techniques. In parallel, the interest in autopsies and its practical knowledge has seemingly been lost.

Pathology in general and postmortal diagnostics in particular play a central role in general medical education and quality assurance. Motivated by this fact, it was our aim to reposition and redefine postmortal diagnostics in a university setting, in part in collaboration with the Department of Surgery of the University Hospital of Bern. In the following, we present our experience, detailing the most important modifications made in the process. The modifications comprised several factors that were conducted within a general change in the structure of the diagnostic units of the institute based on the

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principles of LEAN management [8]. The changes further included those, which are being discussed to have the potential to improve the standing of autopsy in modern medicine—including focusing of staff pathologists, incorporation of data from digital medical records, and interactive case discussions with clinicians as well as students [1]. Finally, the changes included implementation of novel tools in the daily diagnostic routine such as minimally invasive approaches in addition to more "classical" postmortal operative interventions.

Material and methods

In the following, the conditions at the beginning of the project and the modifications that were introduced during the realization of the project "Implementation of the Postmortal Diagnostic (PMD) Approach at the Clinical Pathology Division of the University of Bern" are described. Workflow-related changes followed the principles of the LEAN management [9, 10]. Other changes included establishment of a dedicated PMD staff team, integration of digitalization, and development of new preparation methods, with a special focus on minimally invasive and so-called postmortal operative approaches (Table 1).

Background conditions, patients, and ethical considerations

The Institute of Pathology of the University of Bern is an academic pathology department with several diagnostic (histopathology, cytopathology, molecular pathology, and autopsy) and research units. Clinical postmortal services including autopsies of adults, children (including the perinatal period), and neuropathological investigations are offered to the University Hospital (Inselspital), and several affiliated non-university hospitals. Forensic autopsies are performed in the Institute of Forensic Medicine of the University of Bern which is an independent facility. Between 2010 and 2016, the numbers of clinical autopsies were around 150/year (70% adult autopsies). This corresponds to an autopsy rate of around 6–7% for in-house patients (Inselspital). Exact autopsy rates of external hospitals are not recorded. In the 1990s, the autopsy numbers were considerably higher (i.e., around 700 in 1993). After a preparatory period of more than 2 years, the project started in June 2016 and lasted 1 year. The project was approved by the Ethics Committee of the canton of Bern, including the implementation of novel PMD techniques in autopsies of adult patients (KEK 236/15).

Building a dedicated PMD team

A PMD service including a limited number of pathologists dedicated to postmortal diagnostics was implemented. Before, all 14 staff pathologists were involved. PMD work was separated from the normal histology service schedule of the clinical pathology unit. This is in line with the trend and need for sub-specialization in modern medicine including the field of pathology.

Workflow according to the LEAN management

The complete workflow of the PMD procedures was restructured according to the LEAN management [10, 11] as part of a general reorganization of the entire institute. This had previously been implemented successfully in the cytopathology [12] and clinical pathology unit [13]. In brief, the pillars of this concept, originally described in Japan for the application of industrial workflows [8, 14], are the so-called 5S, namely

Table 1 Problems and measures implemented for improving postmortal diagnostics

Problem	Measures implemented
Pathologists' expertise	Building a core team with four faculty pathologists: - performance of postmortems - case discussions and presentations - clinico-pathological conferences - teaching of residents/MD students
Work process	According to LEAN principles
Rooms	Equipment, attitude and behavior comparable to operating theater (dress code, working areas, etc.). Modern documentation methods (cameras, electronic patient records, screens). State-of-the-art tools (e.g., laparoscopy tower)
Structured reports	In analogy to resection specimens
Quality assurance	Bilateral discussions, interdisciplinarity, implementation of "PMD" approved by ethics commission
Indications	Defining special indications for PMD
Reputation within medical community	Offering MD Master's theses, MD dissertations, publications for residents, and faculty members

Sort (Seiri), Set in order (Seiton), Shine/Sweeping (Seiso), Standardize (Seiketsu), and Sustain (Shitsuke). After detailed recording of the actual state in all aspects of the autopsy unit, these principles were followed rigorously. Unused material was sorted out, a new space organization was implemented, and standardization and permanent monitoring of working-units and workflows were applied.

Four PMD rooms with a total of five autopsy tables were transformed into one adequately equipped postmortal "operating room," one room for classical autopsy, and one room for teaching and presentation purposes. All rooms were equipped and maintained according to LEAN principles. A LEAN conform sign out room, where senior staff members, residents, and medical students sign out cases, was established in analogy to the other diagnostic units of the institute [12, 13] (Fig. 1).

Implementation of a more surgical-based postmortal diagnostic approach

We aimed at gradually replacing classical terms and techniques in favor of a postmortal operative approach, which closely resembles working conditions during classical surgical interventions. All postmortal diagnostics start with a "time-out" where a standardized protocol is completed, including the final check of relevant legal requirements, and possible necessity for non-routine preparation approaches. The postmortal operative approach includes using drapes to cover

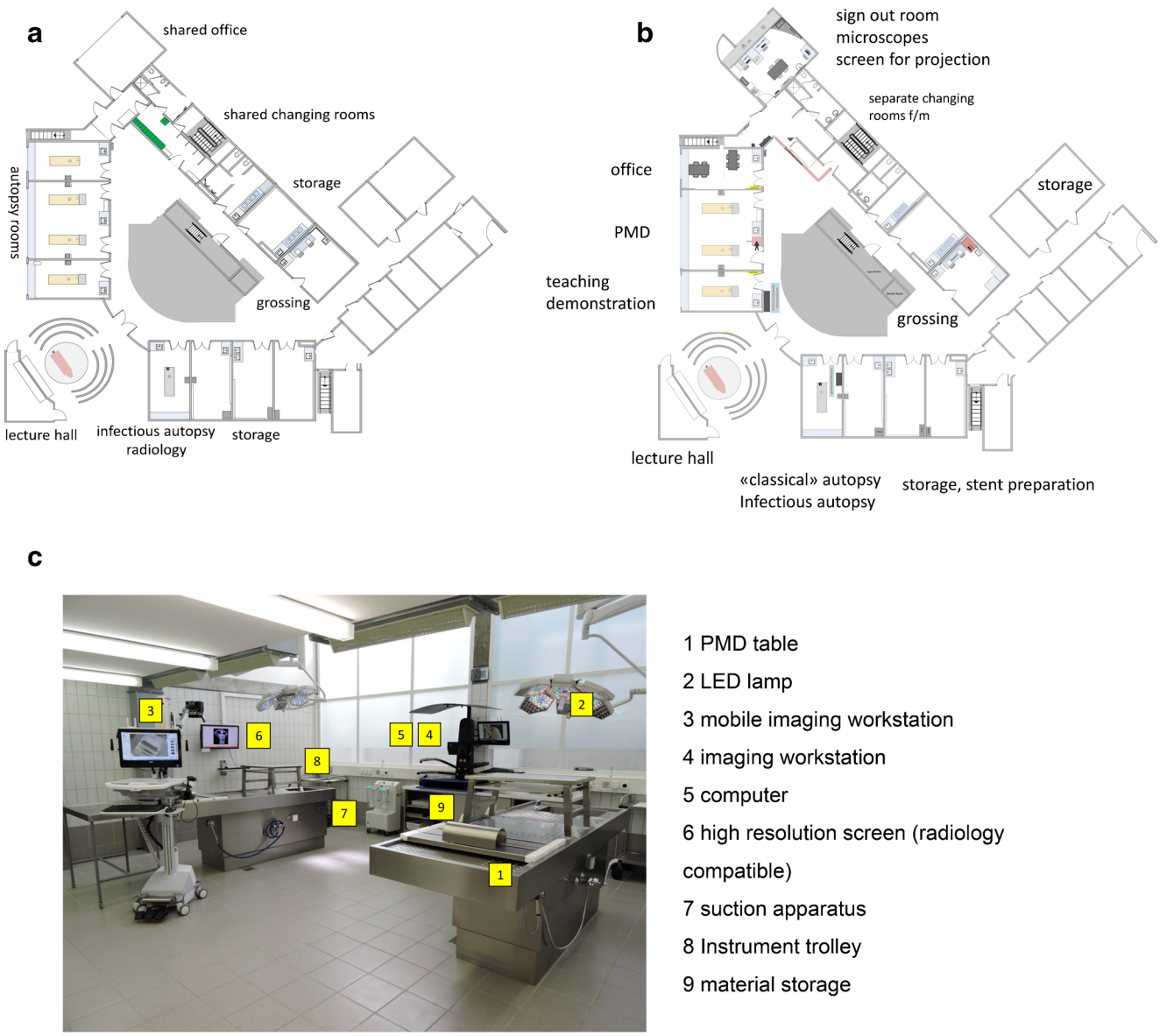

Fig. 1 Room concept. **a** Rooms before LEAN. **b** Rooms after LEAN and restructuring. **c** Postmortal operation room with LEAN conform equipment

all parts of the body not being examined, the usage of suction apparatus (Atmos record 55, Atmos, Lenzkirch Germany), and surgical devices and instruments (iLED lamp, Trumpf, Saalfeld, Germany, Instruments from Olympus, Volketswil, Switzerland). Moreover, we installed a modern facility for photo documentation including a video software (PathStand and PathMobile, Spot-Imaging, Sterling Heights, MI, USA) to enable direct interaction with clinical colleagues, if needed.

Postmortal operative diagnostic approaches (PMOD, i.e., laparotomy and thoracotomy) were applied for the intracavital preparation in order to examine the body cavities, followed by single organ preparation described by Virchow [15]. We implemented the usage of a fast fixation device (FFS, Medite, Dietikon, Switzerland) which allows further processing, e.g., of the heart after 5 h. Standard dissection of the heart was performed after formalin-fixation in toto following incision of the apex and removal of cruor. After fixation, the coronaries were removed and sectioned transversally (with or without decalcification) and the heart was dissected in 1-cm sections from the apex to the midventricular level. Of note, fast fixation is also applicable for brain tissue, which significantly shortens the time until neuropathological work-up. Lungs were also dissected following initial fixation. The lungs are instilled with formalin over the large bronchi, allowing expansion and proper fixation overnight. Dissection of the lungs is then performed using a large knife, resulting in large area sections that are optimal for the evaluation of regional changes and correlation with imaging. At this time, technical modifications of neuropathologic investigation procedures were not part of the study.

Postmortal minimal invasive diagnostic (PMID) procedures were performed in eight adult autopsies during the 1-year period. PMID was performed based on religious restrictions, following the explicit request of the relatives or to assess feasibility in the remaining cases. The investigations were performed or supervised by members of the department of visceral surgery and medicine (BS and co-workers), using a fully equipped laparoscopic device (Olympus, including Endoeye WA50012 A and UES-40 SurgMaster).

Implementation of digital solutions including incorporation of accessible data from medical records

Digital solutions were developed for the order forms, the documentation of the PMD procedures, and the findings and the storage of data which is performed using the pathology documentation system of the institute (PathoWin plus, Basysdata, Basel Switzerland). Moreover, it was recognized that the incorporation of comprehensive clinical information and relevant diagnoses into autopsy reports is essential to ensure an adequate clinico-pathological correlation and correct diagnosis [16]. Indeed, including relevant clinical data into the final postmortal diagnoses clearly enhances the value of autopsy reports. Modern medical data recording allows for rapid and full digital access to patient files to achieve this goal. Within the PMD implementation project we tested, whether more detailed clinical information could lead to more accurate postmortal diagnoses. As an example, we retrospectively analyzed all cases from 2010 to 2014 with the vague diagnosis of "heart failure" as cause of death. Out of 880 reports of adult autopsies those, which stated a cardiac-related cause of death, were included for further analysis ($n = 372$, 42%). Reports were further classified into two subgroups, the first comprising cases with a specific cardiac cause of death and the second comprised the remaining cases with not further specified heart failure stated as cause of death. All patients were then critically reviewed to contain all available clinical and morphological factors, including available data from electronic medical records.

Publicity, research, and education

The project was presented to all the clinics of the university hospital and larger peripheral hospitals in talks and clinicopathologic conferences. The presentations also included aspects of the history and value of postmortal examinations. Moreover, the PMD team took over major duties for students of the medical school, including courses and the supervision of last year's rotation students.

Statistics

For statistical evaluation, IBM SPPS Statistics 24 (IBM Corporation, Armonk, USA) was used. Frequency tables were generated for descriptive analysis. Comparison of groups was performed using the non-parametric Mann-Whitney *U* test for independent samples.

Results

Patients

During the study period, 151 postmortal interventions were performed, among them 102 adults. For 52 of these patients, additional neuropathological examination of the brain was performed. The remaining 49 autopsy procedures were performed for pediatric patients, including the pre- and perinatal period ($n = 32$), for neuropathological investigation of the brain only ($n = 4$), and as neuropathological diagnostic service for the Institute of Forensic Medicine of the University of Bern ($n = 13$).

Dedicated PMD team

The PMD team comprised four board-certified pathologists. The measurements enabled the PMD team to focus on the

various work packages in this project. For example, the team could better concentrate on one-on-one training of the residents, a task previously performed by fellow residents. The introduction and on-site teaching of the residents are now part of the duties of the PMD team. In-house case discussions and presentations for the clinicians, or clinic-pathological conferences are performed or supervised exclusively by PMD staff members. Furthermore, a weekly training session for all residents was introduced to discuss current PMD cases. The PMD team also overtook teaching duties for macroscopy in general, including a daily "macroscopy round" where cases from the grossing routine are presented by the residents and discussed together.

Work flow

The modified room concept and the restructured work process led to a significant simplification of the administrative workflow (including receiving and review of the application forms, scanning, case, and service recording). The covered distance to fulfill administrative duties was reduced from 310 to 10 m.

Implementation of LEAN management significantly influenced the duration of the actual PMD procedures with a reduction from median 2.5 h over the preceding 2 years (range 0.5–5.25) to a median of 2.0 h (range 0.5–4.5; $p < 0.001$) during the project period. This also included the minimally invasive procedures (median 2.0 h; range 1–2.5). Moreover, standardization and simplification of processes thereafter, including histological work up and tissue processing, lead to a more effective workflow in the subsequent work steps as well. Processed histological specimens derived from PMD procedures were thus routinely available within 2–3 days following the PMD procedure. Due to the existence of the dedicated PMD team, the cases could be discussed within a short period after the histology slides were available. A preliminary PMD report containing only the results of the macroscopic evaluation was therefore omitted in favor of one definite PMD report that included macroscopic as well as histological results. This approach parallels our in-house requirements for surgical resection specimens. In most cases, time-consuming additional investigations, such as decalcification, more extensive immunohistochemical analyses, or special cutting procedures for coronary artery stents, were not necessary, i.e., 69/102 cases (67.6%) were finished with just one report. This did not affect the neuropathological diagnosis in most cases which were performed separately. The turn-around times (TAT) for the first report including standard histology were 12 days (range 1–66 days). Median TAT for the final (i.e., second) reports was 14 days (range 3–66 days), in comparison to median 33 days (range 6–114 days) over the preceding 2 years ($p < 0.001$).

Surgical-based postmortal diagnostic approach

Implementation of postmortal operative diagnostic and the change of culture was easy and did only slightly change the routine workflow of autopsy procedures, since it more affected external habits and the surgical access to the body cavities rather than the organ preparation itself. Digital photodocumentation was performed in all cases.

Postmortal minimally invasive diagnostics were performed in eight adult autopsies during the 1-year period. Both laparoscopic as well as thoracoscopic approaches proved to be technically feasible and suitable to answer specific clinical questions in most of the cases. In detail, suspicion of tuberculosis was ruled out by diagnosing organizing pneumonia and negative staining for acid fast bacilli, followed by negative PCR for mycobacterial DNA; clinically suspected metastasized ovarian cancer was confirmed and histology revealed high-grade serous ovarian carcinoma; the diagnosis of diffuse alveolar damage and liver cirrhosis was made in a case with unclear pneumopathy and suspicion of cirrhosis (Fig. 2); suspected pulmonary embolism was confirmed; suspected exacerbation of a clinically diagnosed idiopathic pulmonary fibrosis was confirmed; and a suspected metastasis of a small cell lung cancer in the pancreas eventually causing cholestasis and liver failure was confirmed. However, the primary tumor and lymph node metastases could not be detected by PMID, and the final tumor classification was feasible only after switching to open operative diagnostics. In two patients, PMID was hampered by significant intra-abdominal adhesions due to chronic ascites and previous surgery. A colon perforation could be demonstrated only after switch to laparotomy similar to the detection of a liver abscess causing fatal sepsis and hemolysis (for details, see Table 2).

Integration of digital solutions

The order sheets were made accessible online on the webpage of the institute, and the PDFs can be filled out electronically and sent via secured e-mail (HIN mail gateway; https://www.hin.ch/). Additional hand-written information is scanned and attached. The case documentation is fully electronic in our pathology documentation system. All macroscopic images and selected scanned histology slides are saved under the respective case number.

In the side project regarding the incorporation of accessible data from medical records, we found that out of 372 patients with heart-related cause of death from a 5-year period, a specific cardiac cause such as myocardial infarction (11.2%; $n = 42$), or pericardial tamponade (4.3%; $n = 16$), was stated in 100 (27%) of the initial pathology reports. In 272 patients (73%), the unspecific term heart failure was stated. This is an appropriate diagnosis given that conclusive findings of the heart (e.g., hypertrophy, textural disarray,

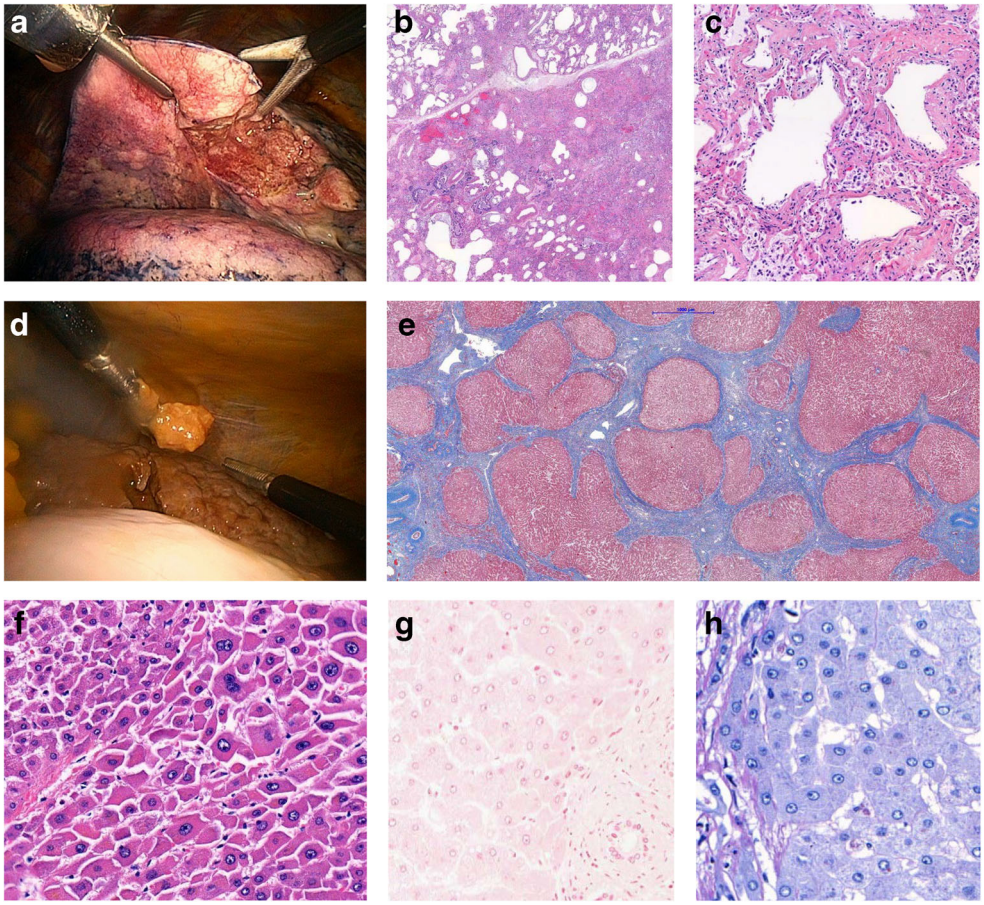

Fig. 2 Example of postmortal minimal invasive diagnostics (PMID) (case 4). **a** Thoracoscopic image. **b**, **c** Histology reveals organizing diffuse alveolar damage. **d** Laparoscopic image of cirrhotic liver. **e** Histology confirms cirrhosis (CAB stain). **f** Presence of large cell changes of the hepatocytes was detected (note the increased and atypical nuclei of the hepatocytes at the right side of the images as opposed to the normal hepatocytes in the left upper corner). **g** No evidence of siderosis (iron stain). **h** No abnormal increase of PAS positive globules detected, which argues against the presence of alpha-1 antitrypsine deficiency (diastase-PAS stain). Immunohistochemistry for alpha-1 antitrypsine was also unremarkable (not shown)

coronary artery scleroses) and other organs (e.g., pulmonary and liver findings; acute congestion) can be demonstrated. Following the retrospective integration of all available information including data from the now accessible electronic medical records, however, a more specific cardiac diagnosis and cardiac cause of death were possible in another 179 patients. This was a marked reduction of cases to 93 (25%) with the unspecific diagnosis of heart failure. Another re-evaluation of these 93 patients revealed the following results: 76 had heart weight equal or more than 400 g (including 43 more than 500 g). Thirty-four at least moderate arteriosclerosis at least of one coronary artery. Twenty-nine had previous heart surgery, 46 suffered from hypertension according to clinical data, 24 patients had one of these factors, and 62 patients had more than one of these factors. The remaining seven patients showed signs of heart failure (e.g., lung and liver congestion) together with other conditions (such as tumors and infections). These conditions would allow the diagnosis heart failure, as most probable reason of death, but a detailed comment, including the exclusion of other reasons of death, should be given in the autopsy report. Apart from the medical aspects, this side-project demonstrates the value of the accessibility to comprehensive medical information from electronic data systems also for postmortal diagnostics. Detailed information about the data of this particular part of the study is visualized in Fig. 3.

Publicity, research, and education—feedback and rates of postmortal examinations

Clinical colleagues appreciated our undertaking. Discussing the possibility of postmortal examinations with the relatives of the deceased could be made easier by being able to offer them the alternatives of a more "surgical" approach, a limited or even minimally invasive procedure. This was supported by an increase in adult autopsies by 38%, from 77 in 2015 to 106 in 2016 (52 to 55 for in-house patients, corresponding to autopsy rates of 5.8% and 6.2%). This general upward trend, however, did not further continue with 103 adult PMD procedures in 2017, and 55 until the end of August 2018. Factors such as cost and time pressure in clinics and reduced awareness of the value of postmortal diagnostics in clinical routine, unfortunately, still exist.

Medical students do benefit from designated courses ("autopsy demonstrations") where organs of postmortal cases are presented and discussed, covering pathomorphological findings as well as clinically relevant pathophysiologic aspects. Medical education in Switzerland includes a Master's thesis followed by a medical dissertation. During the study, five medical students were involved in such projects, two of them have already finished their work

Table 2 List of patients with postmortal minimally invasive or postmortal operative diagnostics

Case no.	Age	Gender	Procedure	Main clinical diagnoses	Clinical question	Most relevant pathology diagnosis	PMID/PMOD successful for answering the clinical question?
1	51	m	Thorascopy	Cardiogenic shock	Rule out tuberculosis	Aspiration pneumonia	Yes
2	68	m	Thorascopy, laparoscopy, thoracotomy, laparotomy[a]	Lung cancer	Tumor staging	Metastasized small cell carcinoma of the lung, pT2, N3, M1b (BRA, LYM, PER, HEP, ADR, OTH)	Yes
3	46	f	Laparoscopy	Ischemic stroke, ovarian cancer	Confirmation of clinical diagnosis ovarian cancer and histology	Serous carcinoma, high grade	Yes
4	63	m	Thorascopy, laparoscopy	Pneumopathy; liver cirrhosis	Unclear pneumopathy; etiology of liver cirrhosis	Diffuse alveolar damage; liver cirrhosis with small and large cell dysplasia	Yes
5	55	m	Thoracotomy	Idiopathic pulmonary fibrosis	Confirmation	Idiopathic pulmonary fibrosis	Yes
6	65	m	Laparoscopy, thoracotomy, laparotomy[a]	Liver cirrhosis, ascites	Cause of peritonitis	Colon perforation	Partly, peritonitis seen in laparoscopy, but perforation confirmed and localized after switch to laparotomy
7	55	m	Laparotomy	Liver cirrhosis	Cause of death	Liver failure, liver cirrhosis	Yes
8	65	w	Laparoscopy, thoracotomy, laparotomy[a]	Acute cholecystitis, septic shock, hemolysis	Cause of death	Liver abscess (*C. perfringens*), hemophagocytosis	No, main finding obtained only after laparotomy

[a] Conversion laparoscopy—laparotomy or thoracotomy

and obtained their medical degree (Dr. med.). Additionally, students in their final year of medical school rotate in the PMD unit during the pathology internship, which is now frequently chosen by our students and booked out several months in advance.

Discussion

Several studies, highlighting the value of postmortal examinations, are available [17–21]. Furthermore, despite modern imaging technics and complex diagnostic tests, current publications continue to demonstrate considerable discrepancy rates between clinical diagnoses and autopsy findings [17, 22–24]. Nevertheless, the decline in autopsy rates is dramatic in many countries, as has previously been comprehensively discussed [1, 16].

One factor, however, that has selectively been ignored, is the contribution of the pathology community itself to this decline. In the last decades, the workload of pathologists has dramatically shifted towards histopathology and molecular pathology. Furthermore, the implementation of digital solutions and comprehensive data analysis may expand the field of pathology. Contrasting with this modernization in the pathology field is the postmortal preparation techniques and the culture in autopsy units, which seem largely unchanged since the time when Rudolf Virchow and Carl Rokitansky practiced [25]. Consequently, knowledge and interest in postmortal diagnostics by pathologists are also decreasing, leading to suboptimal services for clinical colleagues. These colleagues, in turn, may not see the need for autopsies, feeding into a vicious circle ending in the disappearance of autopsy practices [16, 26].

In a cost and labor-intense undertaking, fueled and enabled by motivated personnel, we aimed to address this issue and to implement several aspects of modern medicine and laboratory management into our autopsy unit. Our aim was to transform it into a modern postmortal diagnostic (PMD) unit, accompanied by a change in culture and perception within the rows of the pathology staff itself, extending to our clinical colleagues. This paper highlights the foundations of our modifications and gives insight into some examples in more detail.

We implemented LEAN management principles in workflow reorganization. The benefits of LEAN management on modern laboratory practice, including pathology, have already been discussed in detail before [11, 12, 27, 28]. LEAN is the superior organization concept of all diagnostic units at the institute [12, 13]. In the PMD unit, the most striking improvement following LEAN implementation was the significant reduction in turn-around times, mainly by reduction of waiting times. Indeed, reduced turn-around times are clearly one of the most important factors in pathology reporting in modern medicine [29]. In addition, it should be noted that continuous teaching of both medical doctors as well as medical assistants

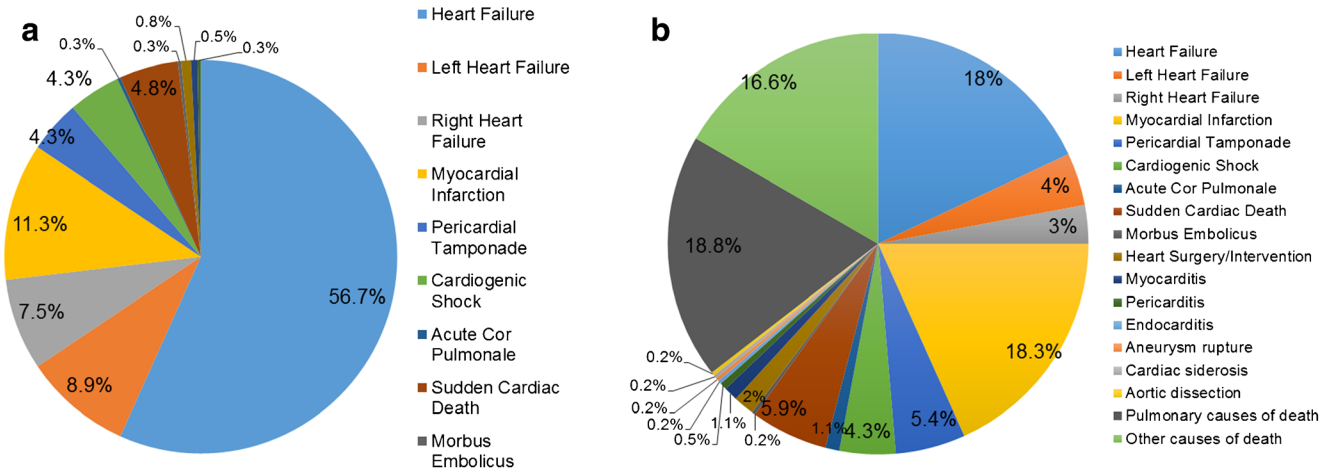

Fig. 3 Improvement of accuracy of postmortal diagnosis by integration of digital data from medical records—example "cardiac failure." **a** Percentages of original diagnoses. **b** Diagnoses after reclassification after implementation of all available clinical data

in the LEAN principles finally led to a sustainable change of culture within the institute and the PMD unit in particular.

With regard to the postmortal diagnostic procedures themselves, macroscopic preparation procedures were adapted towards a more surgical approach including the introduction of time out protocols and general rules of conduct resembling those in place in operating theaters. A further focus of the project was the introduction of novel preparation methods, including minimally invasive approaches.

Minimally invasive autopsies have been proposed as an alternative to classical approaches, in particular in situations where religious or other concerns of relatives or the risk of infection are relevant [30]. Previous studies have already shown promising results with various minimally invasive technics [31–35], including selective asservation of tissue for research [36]. It should be noted, however, that the definition "minimally invasive" in these studies includes several approaches, ranging from imaging guided biopsies to laparoscopic and thoracoscopic procedures. In line with data from the literature, we could demonstrate that postmortal minimally invasive diagnostics ("PMID"), including tissue asservation for histology, is technically feasible. PMID can be implemented in a variety of conditions if standard autopsy has not been requested or not agreed to by next of kin. Based on our current experience, PMID may be particularly useful to specifically address organ- or site-related clinical questions. However, limitations of this approach, as expected, are comparable to those of intravital laparoscopic or thoracoscopic examinations. We are aware of the fact that the introduction of this approach was associated with high personnel and investment effort. Our institute currently charges for the investigations regardless of the procedure according to the Tarmed (national pay scale system for medical service). We do not have recorded the actual costs, since at this stage they would also have included the costs for machines and material. This, however, can be considered as investment, and cost may be "reimbursed" in case of higher autopsy rates due to better acceptance. The duration of the minimally-invasive procedures, however, was within the range of the other PMD investigations.

Minimally invasive approaches have also been considered to be a promising tool for postmortem examinations of pediatric patients [37–40]. While this field could also benefit from technical development towards less invasive diagnostics, in particular in combination with postmortal imaging, we could not include the application of minimally invasive techniques in pediatric patients due to restrictions of the ethics commission at this time. Demonstrating the feasibility of this approach, however, we are now encouraged to expand our experiences onto the pediatric and neonatological group of patients. Apart from the LEAN-related general changes in our PMD unit, we did not include technical modifications of the neuropathological investigations either. At the best to our knowledge, no minimally invasive techniques for postmortal neuropathological examinations have been published so far. The examination of mass lesions, or standardized sampling of defined areas using stereotactic techniques, could represent situations for the application of minimally invasive techniques, ideally combined with postmortal imaging in this field. Similar to laparoscopic and thoracoscopic approaches, however, this would also require special equipment and image guidance causing higher effort compared to the conventional examination of the brain.

Access to digital data files is essential, also as part of quality control. A thorough final evaluation should incorporate clinical as well as autoptic findings into the report. Indeed, the availability of comprehensive and detailed clinical, laboratory, and imaging data allows for a more complete interpretation of the patho-morphological findings. This aspect could clearly be demonstrated in the example of a retrospective analysis focusing on the autopsy diagnosis of heart failure. Moreover, the implementation of informatics tools that are able to compute all available medical information would allow

not only an improved medical performance during the lifetime of the patients but also to deliver an even more precise postmortal diagnosis [26].

Whilst a relevant long-term increase in autopsy rates could not be achieved, a trend in halting declining rates could be accomplished. Furthermore, we have observed that the PMD department and services are generally better perceived not only by the clinical colleagues working in the hospitals but also by staff members, in particular residents, within the institute of pathology itself. The project did make use of modern technologies and implement more "innovative" postmortal technics, but postmortal imaging, a further very promising tool for quality assurance [41–44], was not investigated or included in the possible work-up procedures. Postmortal imaging technics require specialized infrastructure. Sufficient experience and knowledge outside of specialized centers are currently still lacking. Similar to minimal invasive approaches, the contribution of postmortal imaging to diagnostics has to be chosen carefully on a case-based approach. Whilst it can contribute significantly in certain situations, it may be very limited in others, in particular those that require tissue-based analyses, e.g., for tumor typing. On the whole, more specific collaborations between various diagnostic disciplines should be strived for in the field of postmortal investigations in the future.

In conclusion, whilst classical autopsy rates are still declining worldwide, our experience has shown that implementation of a more case-based choice of post-mortem technic, i.e., classical autopsy versus minimally invasive techniques, may encourage clinical colleagues and pathologists alike to pursue postmortal diagnostics. Autopsies need not be restricted to technics implemented and largely unchanged since 100 years, but should expand to include modern diagnostic approaches, including minimally invasive technics and postmortal imaging [41–45]. These changes may be the basis to establish a more defined, active, and up-to-date "postmortal medicine." A change in culture in postmortal diagnostics may contribute to a better reputation with clinicians as well as the general population, in particular in countries with low autopsy rates. It is the pathologists' job not only to preserve but also to further develop this valuable tool for medical quality control as well as educational purposes.

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Contributions RL and AL conceived and designed the study, and wrote, edited, and reviewed the manuscript. AT and BS researched and analyzed data, and wrote, edited, and reviewed the manuscript. MT, AB, YB, DC, and AP analyzed data, and edited and reviewed the manuscript. All authors gave final approval for publication. RL takes full responsibility for the work as a whole, including the study design, access to data, and the decision to submit and publish the manuscript.

Compliance with ethical standards

The project was approved by the Ethics Committee of the canton of Bern (KEK 236/15).

Conflict of interest The authors declare that they have no conflict of interest.

References

1. van den Tweel JG, Wittekind C (2016) The medical autopsy as quality assurance tool in clinical medicine: dreams and realities. Virchows Arch 468:75–81
2. Burton JL, Underwood J (2007) Clinical, educational, and epidemiological value of autopsy. Lancet 369:1471–1480
3. Turnbull A, Osborn M, Nicholas N (2015) Hospital autopsy: endangered or extinct? J Clin Pathol 68:601–604
4. Blokker BM, Weustink AC, Hunink MGM, Oosterhuis JW (2017) Autopsy rates in the Netherlands: 35 years of decline. PLoS One 12:e0178200
5. Chariot P, Witt K, Pautot V, Porcher R, Thomas G, Zafrani ES, Lemaire F (2000) Declining autopsy rate in a French hospital. Arch Pathol Lab Med 124:739–745
6. Erlmeier F, Weichert W, Knüchel R, Andruszkow J (2017) Erwachsenenobduktionen im letzten Jahrzehnt in Deutschland. Pathologe 38:430–437
7. Rodewald A-K, Bode P, Cathomas G, Moch H (2017) Klinische Obduktionen in der Schweiz. Pathologe 38:416–421
8. Liker J (2004) The Toyota Way [Electronic Resource]: 14 Management principles from the world's greatest manufacturer. McGraw-Hill Education Ltd., New York
9. Knowles S, Barnes I (2013) Lean laboratories: laboratory medicine needs to learn from other industries how to deliver more for less. J Clin Pathol 66:635–637
10. Womack JP, Jones DT (2015) Lean solutions: how companies and customers can create value and wealth together. Free Press, New York (reprint)
11. Cankovic M, Varney RC, Whiteley L, Brown R, D'Angelo R, Chitale D, Zarbo RJ (2009) The Henry ford production system: LEAN process redesign improves Service in the Molecular Diagnostic Laboratory. J Mol Diagn 11:390–399
12. Hewer E, Hammer C, Fricke-Vetsch D, Baumann C, Perren A, Schmitt AM (2018) Implementation of a 'lean' cytopathology service: towards routine same-day reporting. J Clin Pathol 71:395–401
13. Blank A, Dawson H, Hammer C, Perren A, Lugli A (2017) Lean-management im Pathologielabor. Pathologe 38:540–544
14. Rubin M, Hirano H (1996) 5S for operators: 5 pillars of the visual workplace. Productivity, Portland
15. Virchow RLK (1880) A description and explanation of the method of performing post-mortem examinations in the dead-house of the Berlin Charité hospital, with especial reference to medico-legal practice, from the Charité-Annalen [tr. by TP Smith]
16. Ayoub T, Chow J (2008) The conventional autopsy in modern medicine. J R Soc Med 101:177–181
17. Sonderegger-lseli K, Burger S, Muntwyler J, Salomon F (2000) Diagnostic errors in three medical eras: a necropsy study. Lancet 355:2027–2031
18. Bieri U, Moch H, Dehler S, Korol D, Rohrmann S (2015) Changes in autopsy rates among cancer patients and their impact on cancer

statistics from a public health point of view: a longitudinal study from 1980 to 2010 with data from Cancer Registry Zurich. Virchows Arch 466:637–643
19. Shojania KG, Burton EC, McDonald KM, Goldman L (2003) Changes in rates of autopsy-detected diagnostic errors over time: a systematic review. JAMA 289:2849–2856
20. Silfvast T, Takkunen O, Kolho E, Andersson LC, Rosenberg P (2003) Characteristics of discrepancies between clinical and autopsy diagnoses in the intensive care unit: a 5-year review. Int Care Med 29:321–324
21. Thurnheer R, Hoess C, Doenecke C, Moll C, Muntwyler J, Krause M (2009) Diagnostic performance in a primary referral hospital assessed by autopsy: evolution over a ten-year period. Eur J Int Med 20:784–787
22. Roulson J, Benbow EW, Hasleton PS (2005) Discrepancies between clinical and autopsy diagnosis and the value of post mortem histology; a meta-analysis and review. Histopathology 47:551–559
23. Kuijpers CCHJ, Fronczek J, van de Goot FRW, Niessen HWM, van Diest PJ, Jiwa M (2014) The value of autopsies in the era of high-tech medicine: discrepant findings persist. J Clin Pathol 67:512–519
24. Wittschieber D, Klauschen F, Kimmritz A-C, von Winterfeld M, Kamphues C, Scholman H-J, Erbersdobler A, Pfeiffer H, Denkert C, Dietel M, Weichert W, Budczies J, Stenzinger A (2012) Who is at risk for diagnostic discrepancies? Comparison of pre- and postmortal diagnoses in 1800 patients of 3 medical decades in east and West Berlin. PLoS One 7:e37460
25. Connolly AJ, Finkbeiner WE, Ursell PC, Davis RL (2015) Autopsy pathology: a manual and atlas. Elsevier Health Sciences
26. Levy B (2015) Informatics and autopsy pathology. Surg Pathol Clin 8:159–174
27. Raab SS, Grzybicki DM, Condel JL, Stewart WR, Turcsanyi BD, Mahood LK, Becich MJ (2008) Effect of Lean method implementation in the histopathology section of an anatomical pathology laboratory. J Clin Pathol 61:1193–1199
28. Serrano L, Hegge P, Sato B, Richmond B, Stahnke L (2010) Using LEAN principles to improve quality, patient safety, and workflow in histology and anatomic pathology. Adv Anat Pathol 17:215–221
29. Alshieban S, Al-Surimi K (2015) Reducing turnaround time of surgical pathology reports in pathology and laboratory medicine departments. BMJ Qual Improv Rep 4
30. Fryer EP, Traill ZC, Benamore RE, Roberts ISD (2013) High risk medicolegal autopsies: is a full postmortem examination necessary? J Clin Pathol 66:1–7
31. Karat AS, Omar T, von Gottberg A, Tlali M, Chihota VN, Churchyard GJ, Fielding KL, Johnson S, Martinson NA, McCarthy K, Wolter N, Wong EB, Charalambous S, Grant AD (2016) Autopsy prevalence of tuberculosis and other potentially treatable infections among adults with advanced HIV enrolled in out-patient care in South Africa. PLoS One 11:e0166158
32. Castillo P, Martínez MJ, Ussene E, Jordao D, Lovane L, Ismail MR, Carrilho C, Lorenzoni C, Fernandes F, Bene R, Palhares A, Ferreira L, Lacerda M, Mandomando I, Vila J, Hurtado JC, Munguambe K, Maixenchs M, Sanz A, Quintó L, Macete E, Alonso P, Bassat Q, Menéndez C, Ordi J (2016) Validity of a minimally invasive autopsy for cause of death determination in adults in Mozambique: an observational study. PLoS Med 13:e1002171
33. Avrahami R, Watemberg S, Daniels-Philips E, Kahana T, Hiss J (1995) Endoscopic autopsy. Am J Forensic Med Pathol 16:147–150
34. Avrahami R, Watemberg S, Hiss Y (1995) Thoracoscopy vs conventional autopsy of the thorax. A promising perspective. Arch Surg 130:956–958
35. Avrahami R, Watemberg S, Hiss Y, Deutsch AA (1995) Laparoscopic vs conventional autopsy. A promising perspective. Arch Surg 130:407–409
36. van der Linden A, Blokker BM, Kap M, Weustink AC, Riegman PHJ, Oosterhuis JW (2014) Post-mortem tissue biopsies obtained at minimally invasive autopsy: an RNA-quality analysis. PLoS One 9: e115675
37. Breeze ACG, Jessop FA, Set PAK, Whitehead AL, Cross JJ, Lomas DJ, Hackett GA, Joubert I, Lees CC (2011) Minimally-invasive fetal autopsy using magnetic resonance imaging and percutaneous organ biopsies: clinical value and comparison to conventional autopsy. Ultrasound Obstet Gynecol 37:317–323
38. Ernst LM (2015) A pathologist's perspective on the perinatal autopsy. Semin Perinatol 39:55–63
39. Sebire NJ, Weber MA, Thayyil S, Mushtaq I, Taylor A, Chitty LS (2012) Minimally invasive perinatal autopsies using magnetic resonance imaging and endoscopic postmortem examination ("keyhole autopsy"): feasibility and initial experience. J Matern Fetal Neonatal Med 25:513–518
40. Menendez C, Castillo P, Martínez MJ, Jordao D, Lovane L, Ismail MR, Carrilho C, Lorenzoni C, Fernandes F, Nhampossa T, Hurtado JC, Navarro M, Casas I, Santos Ritchie P, Bandeira S, Mocumbi S, Jaze Z, Mabota F, Munguambe K, Maixenchs M, Sanz A, Mandomando I, Nadal A, Goncé A, Muñoz-Almagro C, Quintó L, Vila J, Macete E, Alonso P, Ordi J, Bassat Q (2017) Validity of a minimally invasive autopsy for cause of death determination in stillborn babies and neonates in Mozambique: an observational study. PLoS Med 14:e1002318
41. Roberts ISD, Benamore RE, Benbow EW, Lee SH, Harris JN, Jackson A, Mallett S, Patankar T, Peebles C, Roobottom C, Traill ZC (2012) Post-mortem imaging as an alternative to autopsy in the diagnosis of adult deaths: a validation study. Lancet 379:136–142
42. Sonnemans LJP, Kubat B, Prokop M, Klein WM (2018) Can virtual autopsy with postmortem CT improve clinical diagnosis of cause of death? A retrospective observational cohort study in a Dutch tertiary referral centre. BMJ Open 8:e018834
43. Westphal SE, Apitzsch J, Penzkofer T, Mahnken AH, Knüchel R (2012) Virtual CT autopsy in clinical pathology: feasibility in clinical autopsies. Virchows Arch 461:211–219
44. Westphal SE, Apitzsch JC, Penzkofer T, Kuhl CK, Mahnken AH, Knüchel R (2014) Contrast-enhanced postmortem computed tomography in clinical pathology: enhanced value of 20 clinical autopsies. Hum Pathol 45:1813–1823
45. Murken DR, Ding M, Branstetter BF, Nichols L (2012) Autopsy as a quality control measure for radiology, and vice versa. Am J Roentgenol 199:394–401