

RESEARCH ARTICLE

Educational training in laparoscopic gynecological surgery based on ethanol-glycerol-lysoformin-preserved body donors

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ABSTRACT

Purpose: Educational training of laparoscopic skills performed on body donors is considered the gold standard prior to surgery in living patients. Appropriate, safe, and feasible fixation of body donors, reflecting true-to-life conditions of tissues, is an essential prerequisite for training workshops.

Materials and methods: Here we describe and evaluate a modified ethanol-glycerol-lysoformin-based fixation technique. Body donors were fixed by perfusion (70% ethanol, 30% glycerol, 0.3% lysoformin; ca. 20 l) via femoral artery and stored in a humid atmosphere (1% thymol) at 4 °C. Technical equipment included a mobile operating table, endoscopy system with gas insufflation, suction/irrigation pump, standard and electrosurgical instruments. The tissue properties of ethanol-glycerol-lysoformin-fixed body donors and their suitability for laparoscopic surgery were tested and compared to the in vivo situation.

Results: Modified ethanol-glycerol-lysoformin fixation was a simple, cost-efficient and hazard-free procedure, resulting in near-to-life tissue conditions regarding consistency and flexibility, with moderate discoloration and greater viscosity of organs. Key laparoscopic procedures (trocar handling, pneumoperitoneum, blunt/sharp dissection, partial/total removal of organs, bi- or monopolar electrosurgery, suturing techniques) could be performed without difficulty. Multiple reuse of body donors was feasible over one year. Compared to the in vivo situation, the investigation of body donors required a greater degree of gas insufflation and more energy for electrosurgery.

Conclusions: Modified ethanol-glycerol-lysoformin fixation applied to body donors permitted laparoscopic surgery in a realistic and practical manner. Due to its logistic advantages, this technique provides appropriate conditions to train laparoscopic skills and implement novel minimally invasive approaches.

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1. Introduction

In times of limited human and financial resources and the widespread use of minimally invasive surgical techniques, surgeons are obliged to train their surgical skills on a hands-on basis prior to surgery in living patients (Garvin et al., 2008; Holland et al., 2011). Educational training for laparoscopic surgery has been traditionally performed on virtual reality simulators, pelvitrainer and video box devices, or animal models (Hogle et al., 2009; La

Torre and Caruso, 2012; Larsen et al., 2012; Lentz et al., 2005; Schout et al., 2010; Spille et al., 2017; van Velthoven and Hoffmann, 2006). Although these approaches have substantially contributed to laparoscopic skills, their major drawbacks are the poor authenticity of anatomical structures, limited realistic tissue feedback, as well as the obvious mismatch between animal and human anatomy in regard of surgical requirements. Given the complexity of human anatomy and its variations, the practice of surgical skills on body donors prior to surgery in living patients is still regarded as the gold standard (Blaschko et al., 2007; Holland et al., 2011; Katz et al., 2003; LeBlanc et al., 2010; Sharma and Horgan, 2012; Wyles et al., 2011). Accordingly, postgraduate education centers provide body donors for practicing minimally invasive surgical procedures (Giger et al., 2008; Holland et al., 2011).

Factors that limit the use of body donors include their restricted availability, considerable cost of handling and storage, and espe-

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cially the type and suitability of embalming methods. Since the discovery of formaldehyde as a fixative agent for anatomical specimens in the late 19th century, formaldehyde-based fixation is the most commonly used method of body donor preservation (Brenner, 2014). Although this method is economical, its disadvantages include its strong and pungent odor, potential health-damaging effects, and the rigidity of soft tissues (Eisma et al., 2011). In particular, the requirements for laparoscopic surgery on body donors (such as the creation of a pneumoperitoneum, the flexibility and mobility of tissues and organs, realistic tissue feedback) are not fulfilled by this fixation technique.

Consequently, either fresh-frozen body donors or soft fixation techniques have been used for training laparoscopic skills. Among these alternative fixation techniques, Thiel's embalming method has been most widely used (Thiel, 1992). Laparoscopic training workshops based on Thiel-embalmed body donors revealed good preservation of natural colors, true-to-life consistency, flexibility, and haptic properties of soft tissues (Cabello et al., 2015; Eisma and Wilkinson, 2014; Giger et al., 2008; Holland et al., 2011; Porzionato et al., 2015; Prasad Rai et al., 2012; Tjalma et al., 2013; Witte et al., 1999). On the other hand, Thiel's fixation method involves considerable effort (such as combined arterial, tracheal, rectal and intrathecal injection), elaborate storage conditions (storage in large containers filled with Thiel solution over several months before initial use), and expensive chemical compounds.

In view of these limitations, we evaluated an alternative fixation method described by Hammer et al. (2015, 2012) and modified by Shiozawa et al. (2010), based on a mixture of ethanol and glycerol complemented by lysoformin. The study was conducted jointly with the Kiel School of Gynecological Endoscopy at the Department of Obstetrics and Gynecology (University Hospitals of Schleswig-Holstein, Campus Kiel, Germany). The purpose of the study was to add to the range of existing laboratory-based laparoscopic teaching tools in gynecology (such as the pelvitrainer or virtual reality simulators). The suitability of ethanol-glycerol-lysoformin-fixed body donors for laparoscopic interventions including their tissue properties, trocar handling, dissection maneuvers, electro-surgery and suturing were investigated and compared to the in vivo situation in living patients.

2. Material and methods

2.1. Body donors

Body donors (13 women, age range 72–103 years, weight 41–80 kg) were recruited from the body donation program of the Institute of Anatomy, Christian-Albrechts University Kiel, Germany. Prior to their death the donors consented in writing to the use of their bodies for educational and research purposes. Advanced stages of arteriosclerosis and previous abdominal surgery were excluded in order to achieve efficient perfusion fixation and optimal conditions for laparoscopic surgery.

2.2. Fixation technique

2.2.1. Perfusion fixation of body donors

After cleaning and shaving the body donor, two blunt cannulas connected to a common tube were introduced into the femoral artery in cranial and caudal direction. Perfusion fixation was carried out by alternating cycles of injections (30 min) and breaks (20 min) over a period of about 24 h to achieve optimal distribution of the fixative solution administered at a ratio of 0.3 l/kg body weight (15–30 l) (Fig. 1). Interval perfusion was achieved by an electronic timer connected to a peristaltic pump (Watson-Marlow, type 501 DV). In obese body donors, the perfusion time was extended to 36 h

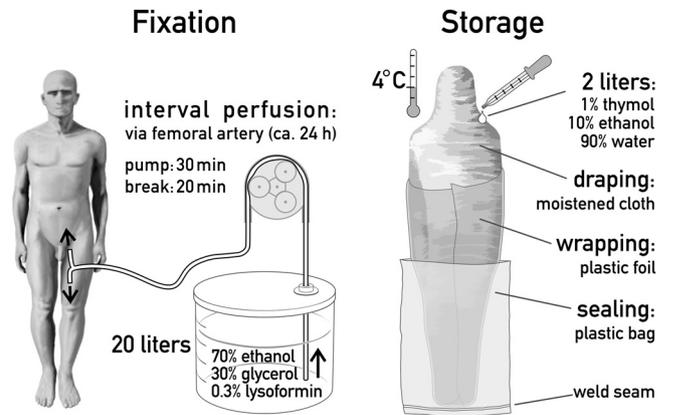


Fig. 1. Schematic overview of ethanol-glycerol-lysoformin fixation and storage of body donors.

and the quantity of fixative solution increased to 30 l. After fixation the cannulas were removed. The arteriotomy and the skin were closed with sutures. The fixation procedure required explosion-proof facilities and technical devices because of the inflammability of ethanol vapors.

2.2.2. Fixative solution

The fixative solution consisted of ethanol (70% vol) and glycerol (30% vol) as fixative agents, complemented by lysoformin (0.3% vol). Lysoformin (Lysoform, Dr. Hans Rosemann GmbH, Germany) is a disinfectant containing 6% formaldehyde, 1.8% glutaral, 5% alkyl ether sulfate, 5% ethanol and 5% anionic tensides. The total cost of the fixative solution (20 l) required for one body donor was about 90 € or 100 \$.

2.2.3. Conservation and storage of body donors

Fixed body donors were draped in cloths moistened with a solution (about 2 l) containing thymol (Sigma-Aldrich, Germany) as conservative agent, which has antibacterial and antifungal properties. 100 g of crystalline thymol was dissolved in 1 l of ethanol and then diluted with 10 l of water, resulting in a final concentration of 1% thymol. Draped body donors were wrapped in a plastic foil and placed in a plastic bag closed at both ends with a weld seam to ensure a humid chamber for storage (Fig. 1). Body donors in sealed plastic bags were stored at 4 °C for up to one year and used several times for laparoscopic surgery.

2.3. Laparoscopic surgery

2.3.1. Laparoscopic equipment

Laparoscopic surgery was performed in operating/dissection rooms at the Institute of Anatomy, Christian-Albrechts University Kiel. Body donors were placed and safely mounted on mobile operating tables (Yuno, Maquet Getinge Group, Rastatt, Germany) which permitted different positions (such as the Trendelenburg or the anti-Trendelenburg position) in order to properly expose the regions of interest. The laparoscopic equipment (Karl Storz GmbH & Co. KG, Tuttlingen, Germany) included an endoscopy system (2D full HD, IMAGE 1-S, 30° optic lens), CO₂ insufflation (electronic Endoflator 264305 20), a rinsing device (Hamou Endomat 263310 20), standard laparoscopic instruments (Karl Storz Clickline), and image processing devices (Image 1 TC 200, Image 1 H3- Link TC 300). Electro-surgery (BOWA-electronic GmbH & Co. KG, Gomaringen, Germany) was performed with MetraLOOP 520-115, ERGO 310D 775-000 and Bowa Arc 400. 10-mm and 5-mm trocars equipped with inflatable cuffs (Kii Optical, Applied Medical, CA, USA) were used to prevent trocar dislocation. In case the trocar entry sites

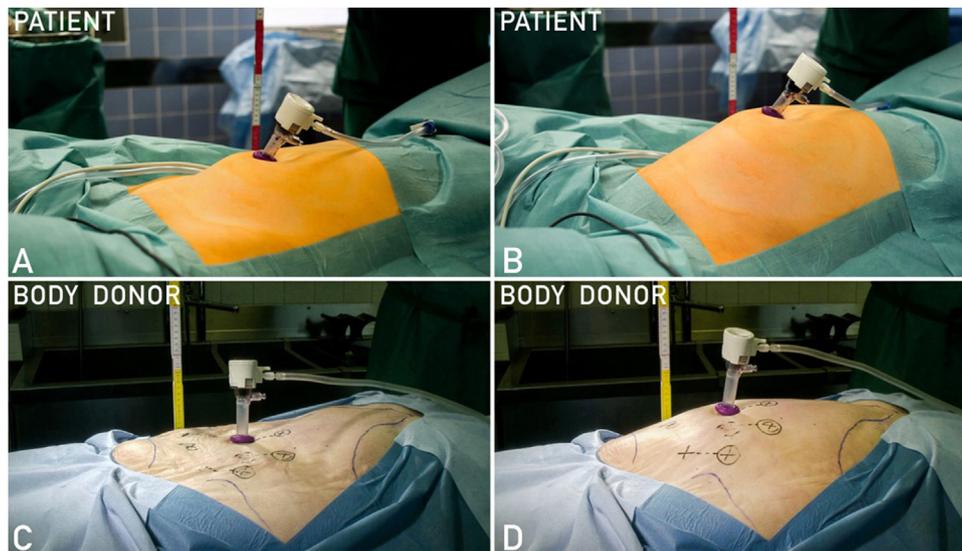


Fig. 2. Creation of a pneumoperitoneum in a patient (A, B) and an ethanol-glycerol-lysoformin-fixed body donor (C, D). A: After disinfection of the skin and draping, the first trocar is placed in subumbilical position. B: Raised abdominal wall (ca. 3 cm elevation) after CO₂ insufflation visualized by a ruler. C: After draping and labeling of relevant anatomical landmarks (such as the iliac crest and the costal arch) and different trocar positions, the first trocar is placed in subumbilical position. D: Raised abdominal wall (ca. 4 cm elevation) after CO₂ insufflation visualized by a ruler.

were not completely gas-tight, they were additionally secured with purse-string sutures (Prolene, Ethicon, Johnson & Johnson Medical).

2.3.2. Laparoscopic procedures

The optic trocar and the laparoscope were inserted into the subumbilical region. Two trocars were placed in the left and right lower abdominal wall, and an auxiliary trocar in the midline at suprapubic position. After creating a pneumoperitoneum by CO₂ insufflation, all abdominal quadrants were explored. The peritoneal cavity was irrigated and suctioned to clean and properly expose the regions of interest. The color, consistency, mobility and flexibility of organs, peritoneal covering, fascia, blood vessels and nerves were evaluated. Blunt as well as sharp dissection maneuvers were performed. Both, monopolar and bipolar electrosurgery for dissecting, sealing and cutting were used, including transection of large organs with monopolar loops (such as supracervical hysterectomy). Intracorporeal suturing was performed on various types of tissue to test the feasibility of the technique and the physical properties of the tissue. The results obtained from procedures on body donors were compared to conditions during laparoscopic surgery in patients at the Department of Obstetrics and Gynecology (University Hospital of Schleswig-Holstein, Campus Kiel). All patients (n=8) were informed prior to the operation and consented in writing to the use of their images taken during laparoscopic surgery.

3. Results

3.1. Fixation technique

A solution of ethanol, glycerol and lysoformin was perfused at a low ratio of about 0.3 l/kg of body donor weight to prevent non-physiological turgor of parenchymatous organs and excessive swelling of interstitial tissues. When interval perfusion was used to permit optimal distribution of the fixative solution, a total volume of 20 l for a normal-weight body donor resulted in sufficient fixation without altering the natural shape and size of the internal organs. However, advanced stages of arteriosclerosis and an interval of more than 48 h between death and the fixation procedure hindered effective fixation. Although fixation as well as subsequent draping

and wrapping of body donors could be easily performed, the following logistic conditions were required: (a) an explosion-proof environment during fixation, (b) sufficient space for the storage of body donors at 4 °C, (c) exposure time of 24–48 h (depending on the body donor's constitution) to room temperature prior to laparoscopic surgery in order to achieve optimum flexibility of tissues and organs. Ethanol-glycerol fixation complemented by lysoformin permitted multiple use of a single body donor for various surgical interventions. Thus, the same trocar entry sites could be used for other laparoscopic procedures, or additional trocars could be placed to address other regions of interest. The body donors could be reused for a period of at least one year without visible alteration of tissue properties, provided that fixation and storage were carried out according to the guidelines described above.

3.2. Trocar placement and pneumoperitoneum

Optic, working and auxiliary trocars could be placed according to the procedures in living patients (Fig. 3). The elasticity of the abdominal wall was similar, and it could be used as a hypomochlion for trocar handling. The umbilical folds could be readily identified along the inner relief of the abdominal wall for orientation. Trocars with inflatable balloon cuffs were best suited to prevent dislocation and gas leakage. The trocar incisions were kept as small as possible and occasionally had to be tightened with purse-string sutures because of post mortem loss of tissue turgor. Insufflation of CO₂ resulted in a pneumoperitoneum with inflation and elevation of the abdomen, similar to that in living patients (Fig. 2). However, body donors needed a higher intraabdominal pressure (about 20 mmHg) with a flow of about 5 l CO₂/min compared to the *in vivo* situation.

3.3. Exploratory laparoscopy

For proper inspection, all abdominal quadrants were cleansed of intraperitoneal exudates by rinsing and suctioning (Fig. 4). An irrigation/suction device was helpful because in most cases the intraperitoneal cavity, especially the rectouterine and vesicouterine pouches, were filled with fluid derived from the fixative solution or previous intraabdominal inflammatory/hemorrhagic

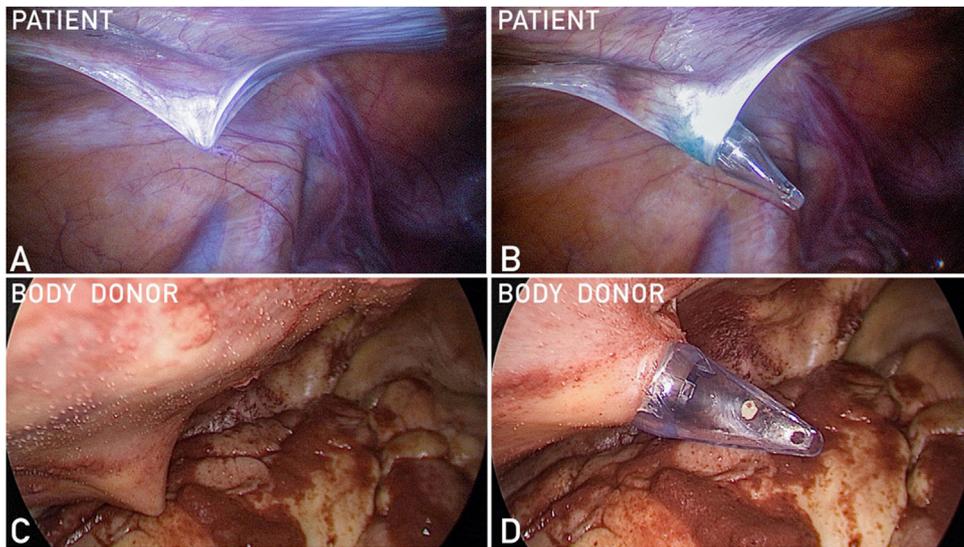


Fig. 3. Placement of an ancillary trocar in the lower abdomen in a patient (A, B) and an ethanol-glycerol-lysoformin-fixed body donor (C, D). The trocar is positioned lateral to the lateral umbilical fold, which contains the inferior epigastric vessels and is easily discernible.

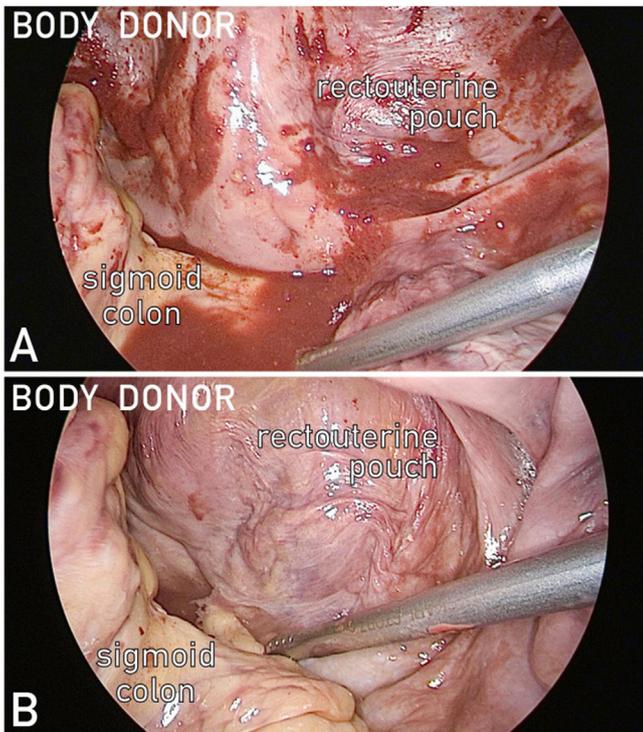


Fig. 4. Irrigation (A) and suction (B) in an ethanol-glycerol-lysoformin-fixed body donor. Residual intraperitoneal fluids are cleansed and washed out by repeated irrigation and suction in order to expose the operating field, such as the rectouterine pouch.

3.4. Color, consistency, and mobility of organs and tissues

Due to the absence of blood flow, the colors were paler than those in the *in vivo* situation. However, the typical coloring of organs and tissues was generally preserved, and permitted a clear distinction between fatty tissue (yellow), parenchymatous organs (dark red), peritoneal covering (whitish pink), connective tissue (white), and muscle tissue (brownish). The quality of color also depended on proper fixation, resulting in a generally darker appearance after delayed or poor fixation. Parenchymatous organs (such as the liver, spleen, or uterus) were not rigid, but showed a consistency close to the natural state and could therefore be easily explored and moved. Although hollow organs (such as the small and the large intestines or the stomach) were not as floppy as in the *in vivo* situation, they could be grasped and shifted by atraumatic forceps to expose the regions of interest. The adnexa, the broad ligament and the parametrial tissue had retained their original state of flexibility, thus permitting all types of dissection procedures. Due to the physical/hygroscopic properties of glycerol (polyol as a backbone for triglyceride lipids), the surface of anatomical structures was smooth, shiny, and covered with a thin oily film. Although this led to greater tissue viscosity in some instances, it did not impair the handling of tissue. While arteries were easily identified, the walls of veins were frequently collapsed due to the increased abdominal pressure. The color (pearly white) and consistency (string-like) of nerves (such as the obturator nerve) resembled the typical features of the *in vivo* situation.

3.5. Dissection maneuvers

Exposure of the regions of interest and tissue dissection were performed with standard laparoscopic instruments by both blunt and sharp dissection. Tissue layers (such as the peritoneum or the parietal pelvic fascia) and pelvic spaces (e.g. prevesical, vesicovaginal, rectovaginal, paraproctium/pararectal, obturator fossa) could be properly opened and dissected. Application of traction and counter-traction on the corresponding layers of tissue permitted the exposure of avascular planes, marked by self-opening connective tissue fibers (“angels hair”) (Fig. 6). Organs, blood vessels, nerves, as well as connective, fatty and lymphatic tissue revealed near-to-life characteristics in regard of exposure, manipulation, dissection, and the haptic feedback to the surgeon. Further evidence

events. After adhesiolysis the abdominal cavity was explored from the epigastric and hypochondriac region down to the greater and lesser pelvis (Fig. 5). Correct positioning of the operating table (Trendelenburg, anti-Trendelenburg, lateral inclination) was needed in order to properly expose the different regions of interest. Given the slightly lesser limpness of intraabdominal organs (such as the greater omentum, small bowel loops, and colon) the Trendelenburg position to 45° had to be used in order to ensure that the structures could be shifted in cephalad direction for optimal exposure of the pelvic cavity.

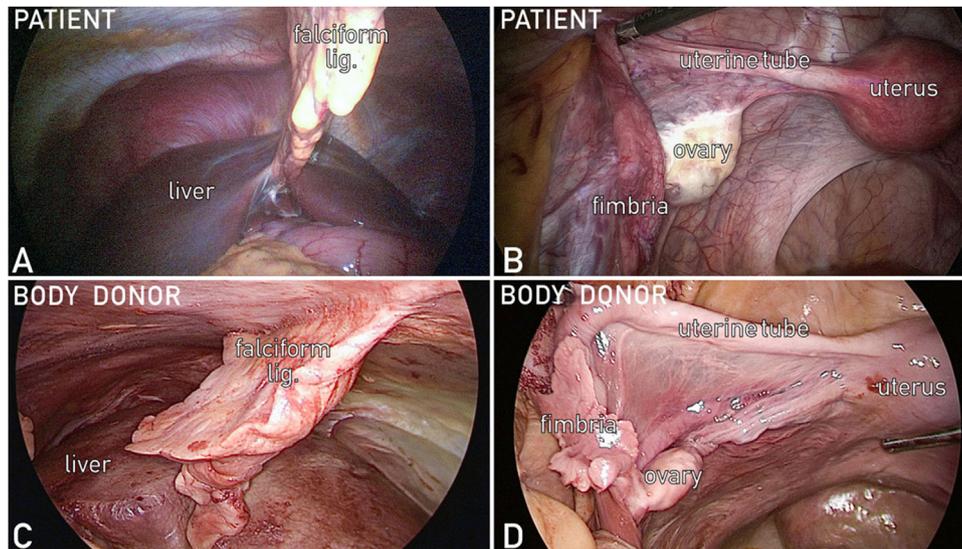


Fig. 5. Exploratory laparoscopy in a patient (A, B) and an ethanol-glycerol-lysoformin-fixed body donor (C, D). The falciform ligament, liver, stomach and anterior abdominal wall are explored in a patient (A) and an ethanol-glycerol-lysoformin-fixed body donor (C). Exposure of the intrapelvic organs in a patient (B) and an ethanol-glycerol-lysoformin-fixed body donor (D); the adnexa and the uterus are lifted with forceps.

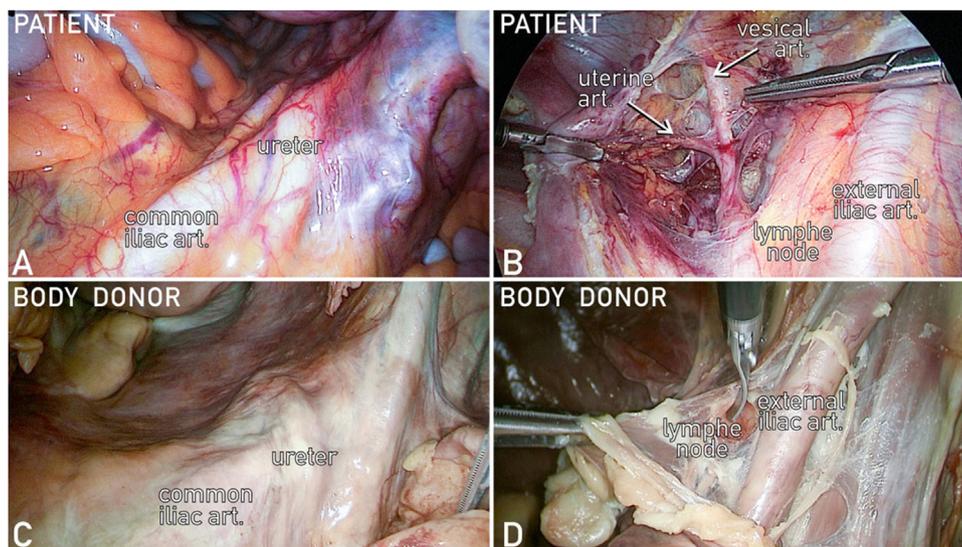


Fig. 6. Dissection procedures in a patient (A, B) and an ethanol-glycerol-lysoformin-fixed body donor (C, D). A: View of the right pelvic sidewall before dissection, showing the bifurcation of the right common iliac artery. The ureter crosses over the right external iliac artery medial to the infundibulopelvic ligament. C: Same topography as in A, in an ethanol-glycerol-lysoformin-fixed body donor. B: Dissection of the retroperitoneal region along the right pelvic sidewall. The ureter is shifted medially to expose the branches of the right internal iliac artery. The uterine and umbilical arteries divide the surgical field into a paravesical and a pararectal fossa. A large lymph node is seen adjacent to the right external iliac artery. D: Same procedure as in B, in an ethanol-glycerol-lysoformin-fixed body donor. Lymph nodes and fatty tissue of the upper obturator fossa are extracted just before reaching the surgical field shown in B.

(although subjective in nature) of convincing realistic conditions was provided by the fact that, when showing photographs or video clips of laparoscopic procedures, surgeons who viewed the recordings could not differentiate between the recordings of body donors and conditions in living patients.

3.6. Electrosurgery

Electrosurgery was performed using different instruments for monopolar and bipolar application. Monopolar and bipolar coagulation, cutting and sealing were feasible in body donors and facilitated the dissection procedure. Adnexectomy with bipolar devices or the transection of parenchymatous organs (such as

supracervical hysterectomy) with a monopolar loop could be performed without any difficulty (Fig. 7). Compared to the *in vivo* situation, more energy was required in body donors to achieve the same effects and velocity of electrosurgery.

3.7. Suturing techniques

Tissue characteristics and behavior in response to needle and suture handling were comparable to the *in vivo* situation. This was true of the suturing of parenchymatous and hollow organs, the peritoneum, blood vessels, and ligaments. Even rigid ligaments (such as the pectineal ligament or the anterior longitudinal ligament of the sacrum) used for colposuspension procedures (e.g. Burch colpo-

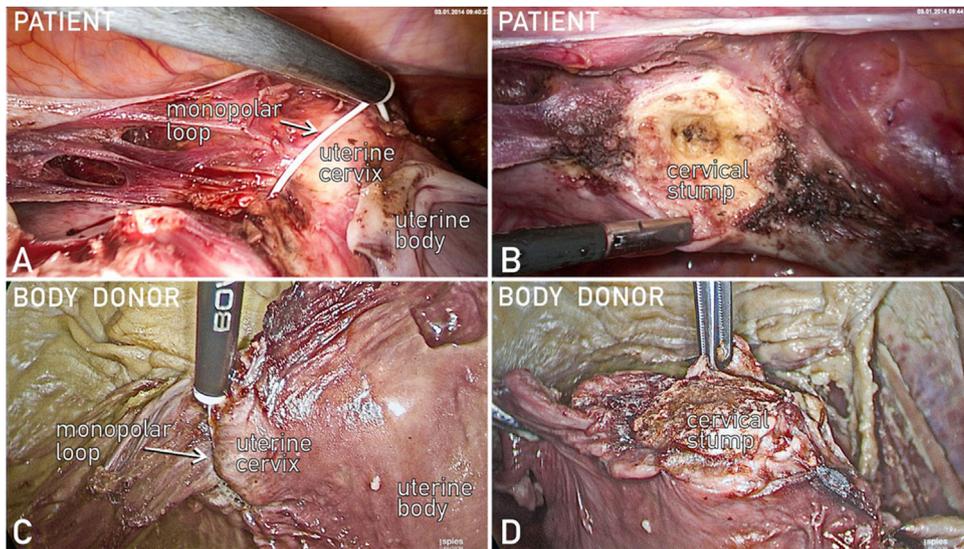


Fig. 7. Application of electro-surgery in a patient (A, B) and an ethanol-glycerol-lysformin-fixed body donor (C, D). A: Use of a monopolar loop during supracervical hysterectomy. B: The cutting surface with clean cutting margins corresponds to the cervical stump. C, D: Same procedure as in A and B, in an ethanol-glycerol-lysformin-fixed body donor.

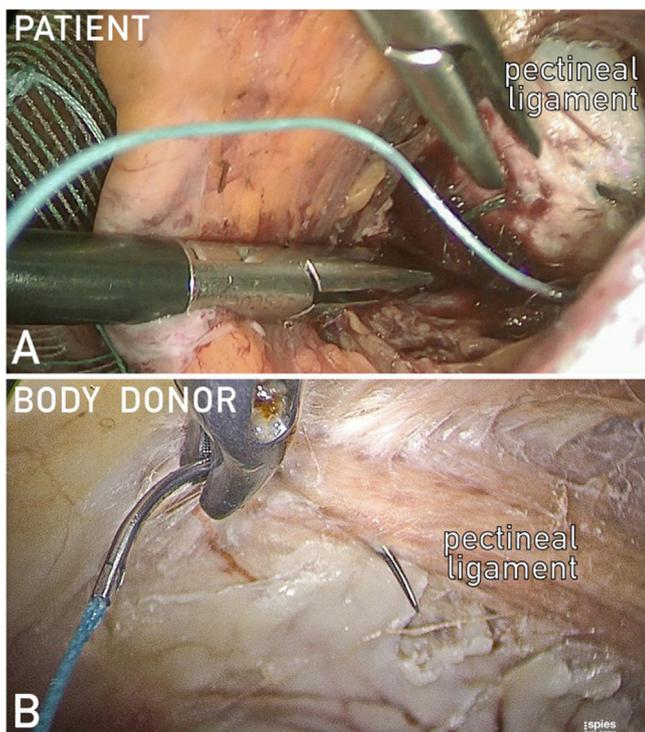


Fig. 8. Intracorporeal suturing in a patient (A) and an ethanol-glycerol-lysformin-fixed body donor (B). A: Tissue manipulation and needle driving to attach a suture to the pectineal ligament. B: Same procedure as in A, in an ethanol-glycerol-lysformin-fixed body donor.

suspension, pectopexy, sacrocolpopexy) could be easily addressed; the ligaments revealed similar properties as those encountered in the *in vivo* situation (Fig. 8).

In summary, ethanol-glycerol-lysformin fixation of body donors as described above combined with appropriate laparoscopic equipment and adjustable operating tables permitted a wide spectrum of laparoscopic procedures such as supracervi-

cal/total hysterectomy, bilateral adnexectomy, lymphadenectomy, and urogynecological procedures.

4. Discussion

4.1. Demand for preclinical educational training in minimally invasive surgery

In the interest of the patient's safety and welfare, the surgeon is required to learn new surgical techniques in an expedient and skillful manner (Rusius et al., 2010). Given the limited human and financial resources in modern medicine, special programs are needed to ensure the comprehensive education of young surgeons (Chen et al., 2004). The future of the human healthcare system depends on a structured and well-funded curriculum of education that provides additional surgical training before direct contact with patients (Hongoro and McPake, 2004). To this end, the surgeon should be given the opportunity to practice his/her skills prior to on-the-job training on live patients in the operating room (Alkatout et al., 2016; Rusius et al., 2010). The acquisition of practical skills is especially important and demanding in advanced surgical procedures such as laparoscopic surgery (Prasad Rai et al., 2012). Although mechanical or virtual trainers, dead or live animals are valuable training tools, several studies have shown the superiority of surgical training in human body donors with regard to haptic conditions, realistic scenarios, and educational benefits (Alkatout et al., 2012; Britt et al., 2015; Cundiff et al., 2001; Eisma et al., 2011; Katz et al., 2003; LeBlanc et al., 2010; Spille et al., 2017; Stefanidis et al., 2013; Wyles et al., 2011). In particular, when novel minimally invasive approaches are implemented, preclinical surgical workshops based on body donors are mandatory to optimize the learning curve and minimize complication rates (Francis et al., 2017).

4.2. Requirements for body donor fixation

The apparently easiest way to use body donors for educational surgical purposes is to perform interventions on fresh-frozen specimens. However, despite its obvious advantages this approach is time consuming because of laborious defrosting procedures. It calls for large and expensive deep-freezing facilities, and is associated

with considerable loss of tissue quality and tissue decay, especially after multiple reuse (Blaschko et al., 2007). To overcome these limitations and optimize conditions for surgical training, the bodies of donors are subjected to fixation prior to their use (Eisma et al., 2011). The optimal fixation technique should fulfil the following requirements: (a) it should be safe and harmless, (b) permit fast and simple fixation, (c) preserve the true-to-life anatomy and tissue consistency of the body, (d) be odorless or have a tolerable odor, (e) be economical, (f) permit storage for a prolonged period of time, and (g) permit multiple use with unaltered tissue quality. Since traditional formaldehyde-based fixation techniques do not fully meet these criteria, alternative fixation techniques have been used for laparoscopic surgical training, such as Thiel's fixation, the saturated salt solution method, soft or lightly embalmed body donors (Cabello et al., 2015; Eisma and Wilkinson, 2014; Giger et al., 2008; Hayashi et al., 2016; Holland et al., 2011; Levine et al., 2006; Porzionato et al., 2015; Prasad Rai et al., 2012; Tjalma et al., 2013; Udomsawaengsup et al., 2005; Witte et al., 1999).

More recently, a fixation technique based on ethanol/glycerol was described as a potential alternative to formaldehyde and phenol embalming (Hammer et al., 2012), and compared to a modified version of Thiel's fixation (Hammer et al., 2015). The authors concluded that this modified method of Thiel's fixation, although six times more expensive, was ideally suited for clinical workshops, whereas ethanol-glycerol fixation is more appropriate for student dissection courses because of the rigidity of soft tissue. To prevent such induration, we modified the original protocol for ethanol-glycerol fixation in accordance to Shiozawa et al. (2010): we increased the fraction of glycerol (3–10% vol–30% vol), reduced the fraction of ethanol (90–97% vol–70% vol) and added lysoformin (0.3% vol). Moreover, to prevent excessive swelling of interstitial tissues and organs, the ratio of the injected fixative solution was reduced (0.7 l/kg body weight to 0.3 l/kg body weight), resulting in a total volume of about 20 l instead of 50 l. The major risks of increasing the glycerol content and reducing the total quantity of fixative solution are a) the formation of mold, and b) insufficient tissue fixation (Hammer et al., 2012). However, the addition of lysoformin as a disinfectant and the exposure of the body donors to thymol as a conserving agent during storage in a cooled humid atmosphere resulted in no fungal growth or tissue decomposition. Although lysoformin contains both formaldehyde (6%) and glutaral (1.8%), final concentrations in the fixation solution were reduced to 0.018% and 0.005% respectively.

As mentioned previously by Hammer et al. (Hammer et al., 2015; Hammer et al., 2012), ethanol-glycerol fixation and thymol conservation is harmless, easy to handle in regard of fixation and the storage procedure, associated with a thyme-like pleasant odor, and is economical (per donor: 70–90 €/80–100 \$ for the present procedure versus 400–500 €/470–590 \$ for Thiel's fixation). We were able to reuse the body donors several times for laparoscopic interventions over a period for at least one year; the quality of tissue was preserved. Most importantly, the appearance, consistency and flexibility of tissue were very similar to those of living tissue. These features are known to be indispensable prerequisites for laparoscopic surgery. Nevertheless, the following restrictions are worthy of mention: ethanol-glycerol-lysoformin fixation requires: 1) an explosion-proof environment, 2) sufficient space for the storage of body donors at 4 °C, 3) removal from cold storage 24–48 h prior to laparoscopic surgery in order to achieve adaptation to room temperature, 4) ethanol-glycerol-lysoformin fixation is associated with a slight discoloration of tissue, and 5) greater viscosity/stickiness of organs. However, the large majority of the properties required of a fixative solution for performing laparoscopic surgery on body donors are fulfilled by this method of modified ethanol-glycerol-lysoformin fixation. The advantages of the procedure clearly outweigh its limitations.

4.3. Feasibility of laparoscopic surgical procedures

The feasibility of laparoscopic gynecological surgery was tested previously in fresh–frozen, lightly embalmed, or Thiel fixated body donors (Cundiff et al., 2001; Levine et al., 2006; Tjalma et al., 2013). By using ethanol-glycerol-lysoformin-fixated body donors we could obtain similar results as outlined in these studies. In particular the prerequisites for laparoscopic interventions (including trocar insertion and the creation of a pneumoperitoneum), general maneuvers (such as rinsing and suction, blunt and sharp dissection, the exposure of pelvic and retroperitoneal spaces, handling of blood vessels, lymph nodes and nerves), as well as specific procedures (suturing techniques, monopolar and bipolar electrosurgery) were readily achieved. Virtually all types of laparoscopic gynecological procedures could be performed, such as supracervical/total hysterectomy, bilateral adnexectomy, pelvic and retroperitoneal lymphadenectomy, and urogynecological procedures.

The surgical handling of ethanol-glycerol-lysoformin-fixed body donors differed from the *in vivo* situation in the following aspects: 1) The higher glycerol content created an oily film on organ surfaces and led to less “floppy” intraperitoneal organs as well as “stickiness” of tissues, requiring accentuated positioning of the operating table for optimal exposure of regions of interest. 2) Intraperitoneal pressure and CO₂ flow had to be increased in order to achieve an ideal pneumoperitoneum. 3) Repeated rinsing and suction were required to remove intraperitoneal fluid. 4) A higher level of energy had to be used for electrosurgery in order to achieve optimal coagulation, cutting, and sealing effects. However, once the surgeon is familiar with these technical requirements, the procedural steps of laparoscopic interventions are similar to those performed in living patients.

5. Conclusions and future perspectives

The evaluation of ethanol-glycerol-lysoformin fixation applied to body donors for the purpose of preclinical training of laparoscopic surgical skills showed that the large majority of the required criteria are fulfilled by this procedure. While several aspects are shared in common with Thiel's fixation (e.g. less harmful, true-to-life properties, multiple reuse), the modified fixation technique is easier to handle and cost-efficient and, thus, provides an ideal setting for surgical training workshops as well as research and development projects with the aim of implementing novel laparoscopic devices and approaches.

Concerns regarding ethical issues and the patients safety in “reality surgery” or “live surgical broadcast” have been voiced recently (Finch et al., 2015; Williams et al., 2011). In this context, laparoscopic surgery performed on ethanol-glycerol-lysoformin-fixed body donors may complement or even serve as an alternative to live demonstrations of operations, which have nowadays become an integral part of surgical workshops and conventions. Future experiences and comparative studies will be needed to determine the added value of this approach in performing minimally invasive surgery on adequately fixed body donors, and its impact on surgical education and technical innovations.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at <https://doi.org/10.1016/j.aanat.2018.10.002>.

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