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ORIGINAL ARTICLE

Subxiphoid hernia, definition and repair: an international delphi consensus

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Abstract

Purpose Subxiphoid incisional hernias (SIH) are rare and challenging to repair, often occurring post- cardiac surgery after sternotomy and pericardial drainage. The literature on SIH is limited, with small patient cohorts and no established consensus on optimal repair strategies published yet. This present study aimed at proposing the definition and the surgical management and decision-making processes for SIH repair through an international Delphi consensus among expert surgeons.

Methods Using a modified Delphi technique, 69 international abdominal wall surgeons were invited. Three rounds were conducted to reach consensus on the definition, characteristics, classification, preoperative imaging and surgical approaches for SIH. Consensus was defined as more than 70% of agreement on 32 statements across 12 topics.

Results Sixty-nine experts were enrolled from 5 continents. Concerning definition of SIH, consensus was reached: a defect where the M1 part represents the most challenging and representative part. According to the expert panel, a mesh should be used in an extraperitoneal position. Both open and minimal invasive surgical (MIS) approach (E-TEP and/or ventral TAPP) are viable for W1 (< 4 cm) SIH repair. Achieving sufficient mesh overlap (> 5 cm) and defect closure are the 2 primary goals during SIH repair, whatever the approach and the technique. Expert panel agreed that a solid understanding of the anatomy is crucial and difficult in this area, due to the proximity of bony structures. For cranial overlap, exposing the central tendon of the diaphragm after cutting the posterior rectus sheath horizontally reached consensus. Concerning lateral overlap, the panel agreed on a retro rectus repair with TAR for ≥W2 hernia, while total preperitoneal repair is not. Mesh fixation is deemed unnecessary if adequate overlap is achieved. In case of difficulties of closure, only TAR might be helpful, with bridging as a last resort. They agreed that SIH ≥W2 should be referred to an expert hernia center.

Conclusion This Delphi consensus defined SIH and was an opportunity to emphasize the anatomy of the subxiphoid region. It opens the way for future strong studies on the subject, leading for recommendations.

Keywords Complex hernia · Delphi consensus · M1 hernia · Subxiphoid hernia · Ventral hernia

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Introduction

Subxiphoid incisional hernias (SIH) are rare ventral hernias, occurring at the upper end of the midline under the xiphoid process. They typically result from cardiac surgery when the incision extends to the abdomen [1] (Fig. 1), but any laparotomy incision that reaches the xiphoid can cause a SIH.

The precise incidence of SIH is difficult to ascertain, largely due to their asymptomatic nature and short follow-up of series studying median sternotomies. In a literature review, the incidence of SIH after median sternotomy for cardiac surgery ranged from 0.81–3.44% [2], similar to the results from a large retrospective study published by a single cardiothoracic center [3]. The incidence of SIH caused by subxiphoid laparotomies is unknown.

According the European Hernia Society (EHS), primary subxiphoid hernia doesn't exist [4], whereas SIH can be classified as M1, also called "subxiphoidal group" that extends from the xiphoid process till 3 cm caudally [5]. The EHS classification suggests that "hernias close to bony structures should have separate subgroups", as the definition, classification, pathology, treatment and outcome of SIH remain underexplored and should represent a precise and distinct entity.

Fig. 1 SIH after pericardial drainage

SIH are finally poorly understood and challenging to repair, probably due to the complex anatomy in this area, leading to difficulties in creating extra peritoneal space for mesh placement and fixation. As it is surrounded by the xiphoid process, the sternum, the last rib cartilages and the close anatomical relation with the diaphragm posteriorly, SIH resides in a complex environment of muscles, tendons and aponeurosis coming both from the abdomen and the thorax. The subxiphoid area seems difficult to repair, due to the proximity of the diaphragm, the pericardium and the lack of muscular support. Additionally, these patients with previous heart failure are often vulnerable with multiple comorbidities [6], complicating repairs further.

The optimal mode of approach of the SIH is unknown and literature is sparse on the matter with only retrospective cohorts and 2 available reviews with a small number of patients. One published in 2007 including 7 retrospective studies with a total of 113 patients [7] and another in 2020 including 8 retrospective studies with 5 similar than the previous one, reporting 132 patients [2]. Revealing wide variations in definitions, per and postoperative data and follow-up periods, these reviews make difficult to established standardized techniques or to report recurrence and complication rates [3]. The largest series published in 2020, based on the Herniamed registry, included 208 patients with one-year follow-up [6]. Authors reported heterogenous techniques, including open or laparoscopic repair, absorbable and non-absorbable meshes with various placements (sublay, onlay, IPOM and IPOM+) and fixation [2, 3, 6–9]. Furthermore, the definition of SIH was not clearly reported, representing only M1 incisional hernia or only located below the xiphoid process. In the absence of consensus, the SIH repair technique currently depends on surgeon experience or preference, including open, laparoscopic and robotic repairs, in different layers.

No optimal repair suggestions could be gleaned from the current literature. A Delphi consensus was initiated to clarify SIH definitions and surgical management. An expert panel reviewed the anatomical basis, specific features and challenges of SIH repair. The purpose was not to create recommendations on the topic but to discuss results, encourage further research and assist in clinical decision-making.

Methods

Delphi method

The Delphi process is a structured communication technique originally developed in the 1950s acting as a forecasting tool [10]. For this study, we conducted a modified Delphi technique by gathering expert opinions and informed judgments to achieve consensus on some aspects of SIH definitions and management.

Panel selection

Expert panel selection was performed by three expert surgeons (A. D and Y. R from France and S.B from India). The first selection concerned international abdominal wall surgeons based on their expertise in complex hernia surgery and on their influence and publication. Then the recruitment was based on their affiliations with hernia societies and their participation in previous Delphi process [11]. Lastly, efforts were made to include mostly academic surgeons, from all continents, with different approaches (in MIS, robotic and open surgery) to avoid biased answers. Finally, 69 expert surgeons were invited via email and agreed participation: 12 from the USA, 9 from France, 3 from Italy, 6 from Spain, 7 from the UK, 2 from Holland, 1 from Austria, 1 from Romania, 2 from Switzerland, 4 from Belgium, 2 from Portugal, 4 from Denmark, 4 from Germany, 1 from Greece, 1 from Norway, 3 from India, 2 from Mexico, 3 from Australia, 1 from Turkey and 1 from Colombia. Experts were asked to provide their answers independently and anonymously. When more than 70% of identical answers were collected, they were considered as consensus agreement [11].

Delphi rounds

Same three expert surgeons performed all questionnaires, analyzed the results of each round and drew up new questionnaires at each stage of the process. They were not allowed to answer the questionnaires. Before performing the first questionnaire, A. D and Y. R independently performed a deep review of literature focusing on definitions, preoperative management and the surgical techniques of repair. No strong evidence was found. Therefore, the questions forming the first questionnaire strictly focused on the definition, characteristics and the repair of SIH. After several discussions and meticulous changes concerning terminology and vocabulary, the 3 members agreed on the entire questionnaire.

Round 1

The first round included 25 multiple choice questions, assigned into 12 sections: EHS classification, repair difficulties, preoperative imaging, main objectives for surgical repair, surgical repair according to the size of hernias, mesh position, surgical approaches according to the size of hernias, mesh fixation, methods to ensure enough overlap for the mesh, methods to ensure complete closure and possible need for expertise. The sections were converted into a well-structured questionnaire using the online survey application Google Forms. Open-ended questions asking for the expert's

opinions were added at the end of each section. All answers collected from round 1 were analyzed and summarized by the expert trio. When items reached consensus, they have been removed from further iterations. When a consensus was not achieved on an item, new questions were redesigned based on the expert answers and comments from the first round.

Round 2

All panel experts received a summary of the results from the first round. This process allows experts to reconsider their initial answers in the light of the collective opinions provided by their peers. The second questionnaire included statements where the only possible answers were "agree/disagree". After each question, a free text was available for comments. The same process as round 1 was repeated on the results of round 2 to create the questionnaire for the round 3.

Round 3

Same process as round 2 was applied.

Distribution and data analysis

Results consisted in a descriptive analysis and were presented as percentage of consensus.

Results

Round 1

All 69 experts answered to the questionnaire. Seven questions achieved consensus and are reported in Table 1. Briefly, the panel agreed for the etiology (sternotomy), for the use of a mesh with a 5 cm overlap at least and against IPOM repair. No consensus was reached regarding EHS classification, preoperative imaging, types of approach nor ideal mesh position.

Round 2

Sixty-five experts answered to the questionnaire. Eighteen questions achieved consensus and are reported in Table 2. Briefly, the panel agreed on the necessity of closing the midline (90.8%) and not to perform a systematic component separation (81.5%). They also agreed on the extraperitoneal position for the mesh (78.5%): retro rectus (in the middle) and pre-peritoneal laterally (after a TAR if necessary) but not entirely pre-peritoneal (70.8%). Concerning surgical techniques, E-TEP and/or ventral TAPP are the preferred repair methods for W1 (< 4 cm) SIH in case a minimal-invasive (MIS) approach (75.4%) and a retro rectus repair (and not totally pre-peritoneal) when open repair is performed for ≥ W2 (≥ 4 cm) SIH (86.2%). Concerning the techniques to ensure a superior overlap, the dissection behind the xiphoid process (73.8%) until the central tendon of the diaphragm (84.6%) after cutting the posterior rectus sheath of rectus muscle (78.5%) reached consensus.

No preferred type of fixation reached consensus (glue, self-fixating meshes and tackers were rejected), nor the uselessness of fixation for both open and MIS surgery (58.5% and 55.4%, respectively). No consensus was reached concerning the preferred open approach for small W1 (< 4 cm) nor concerning MIS approach for > W2 SIH. No preferred procedure to achieve complete closure of the midline reached consensus (anterior component separation and peritoneal flaps were rejected). These sections have been completely reformulated for Round 3.

Round 3

Fifty-six experts answered to the questionnaire. Eight questions achieved consensus and are reported in Table 3. Briefly, definitions of SIH reached consensus (73.2–78.6%). The panel attributed more consensus to the necessity of mesh overlap than for the necessity of fixation (78.6%) or for the type of approach (MIS or open) for small W1 (< 4 cm) SIH. Concerning procedure to ensure medial muscle closure, the panel agreed that component separation techniques give limited effect in the subxiphoid area and bridging the defect may the only solution as a last resort (81.3%).

Table 1 Consensus obtained from round 1

1. The biomechanics for SIH are different from other incisional hernia (M2 to M5)	73.5%
2. It is difficult to fix a SIH because of the proximity of the bony structure	91.2%
3. SIH are usually caused by a sternotomy	89.9%
4. IPOM should not be recommended	72.1%
5. A no mesh repair should not be recommended	97.1%
6. The key point for the surgical repair is to use a large mesh with > 5 cm overlap	79.7%

Table 2 Consensus obtained from round 2

1. Would you consider SIH difficult to fix because of the difficulty to close the midline	81.5%
2. Would you consider SIH difficult to fix because it requires a solid knowledge in anatomy	75.4%
3. One of your first objective is to close the midline	90.8%
4. One of your first objective is to perform a systematic posterior component separation	81.5% disagree
5. For SIH repair, the best option for the mesh position is retro rectus (in the middle) and pre-peritoneal laterally (after a TAR if necessary)	78.5%
6. The ideal approach in case of MIS for < 4 cm (W1) SIH would be E-TEP and/or ventral TAPP	75.4%
7. The ideal approach in case of open surgery for ≥ 4 cm (≥ W2) SIH would be a retro rectus repair with a TAR if needed	86.2%
8. The ideal approach in case of open surgery for ≥ 4 cm (≥ W2) SIH would be a totally pre-peritoneal repair	70.8% disagree
9. For open retro rectus / preperitoneal / retro muscular SIH repair, the preferred fixation method would be self-fixating meshes	70.8% disagree
10. For open retro rectus / preperitoneal / retro muscular SIH repair, the preferred fixation method would be glue	73.8% disagree
11. For minimal invasive retro rectus / preperitoneal / retro muscular SIH repair, the preferred fixation method would be tackers	92.3% disagree
12. One of the techniques to ensure superior overlap is to dissect behind the xiphoid process	73.8%
13. One of the techniques to ensure superior overlap is to dissect until the central tendon of diaphragm	84.6%
14. One of the techniques to ensure superior overlap is to cut posterior sheath of rectus muscle	78.5%
15. To ensure complete closure of the defect in case of difficulties, the ideal technique is to perform an anterior component separation	76.9% disagree
16. To ensure complete closure of the defect in case of difficulties, the ideal technique is to perform a peritoneal flap	73.8% disagree
17. To ensure complete closure of the defect in case of difficulties, bridging if component separation is not enough may be a solution	83.1%
18. The repair of ≥ 4 cm (≥ W2) subxiphoid incisional hernia need a specialized abdominal wall surgeon	90.8%

Table 3 Round 3, questions that achieved consensus

1. About the definition of a superior midline hernias, a SIH is a hernia where the M1 part represents the most challenging part	78.6%
2. About the definition of a superior midline hernias, a SIH is a hernia where the M1 part is the most representative part	73.2%
3. Exposure of the central tendon of diaphragm can be considered as an indicator of adequate cephalic dissection and enough overlap	80.4%
4. For elective repair of small W1 (< 4 cm) SIH, both MIS and open approaches seem equal, the goal is the overlap and the closure of the midline	73.2%
5. For open surgery, fixation is not necessary in most cases if enough overlap is achieved	78.6%
6. In case of MIS surgery, fixation is not necessary in most cases if enough overlap Is achieved	73.2%
7. Despite limited impact for rectus medialization in this area, a TAR may be an option to close the defect	75%
8. Despite limited impact for rectus medialization in this area, Intraoperative Fascial Traction may be an option to close the defect	71% disagree

Discussion

SIH definition

SIH has not been clearly defined yet [2, 3, 6–9]. The EHS classified M1 incisional hernia as part of the "subxiphoidal group" spanning from the xiphoid process to 3 cm caudally [5] (Fig. 1). However, this classification also suggests that "hernias close to bony structures should have separate subgroups". The lateral extension, distance to the last rib cartilage and the inferior edge of the xiphoid process remain undefined. In the present Delphi study, reaching a consensus on the definition of M1 hernias was particularly challenging although the panel agreed that the biomechanics for subxiphoid hernia are distinct from other incisional hernia (73.5% consensus) and that SIH are difficult to manage due to the proximity of bony structures (91.2% consensus). Two specific definitions reached consensus, aligning with that of the EHS: a SIH is a defect where the M1 part represents the most challenging (78.6%) and the most representative (73.2%) part. Therefore, the definition of EHS on SIH should be used.

Regarding primary subxiphoid hernias, 58% of the panel experts reported never having encountered them, implying that 42% of them claim that it may exist. Nevertheless, EHS classifications [4, 5, 12] did not report primary subxiphoid hernias a separate entity. For these reasons, they are probably under reported in the literature and the present study focuses only on incisional hernia.

SIH incidence

The reported incidence of SIH from specialized retrospective studies ranges between 1% and 4.2% [1–9]. The true incidence is difficult to estimate for two reasons: first, many SIHs are asymptomatic and do not require repair [7] and second, no series with long-term parietal complications data following median sternotomies are available [13]. A study involving 24,000 median sternotomy reported a 0.5% SIH repair rate after a mean follow-up of 48 months [1, 7]. According to the Herniamed registry in 2020 [6], the 1,626 SIH repairs accounted for 1.9% of the total 85,076 incisional hernia repairs. In the present study, 41.2% of expert surgeons reported having operated on between 20 and 50 SIHs, 30.9% on more than 50 and 27.9% on fewer than 20. The recurrence rate may range from 10 to 30% after a median follow-up period of 20 to 48 months [6], highlighting the need for a long term follow-up. Interestingly, the modified technique of sternotomy with paraxiphoid section and no section of the linea alba may reduce the rate of SIH [14].

Literature review and Delphi results concerning SIH repair

The available literature on SIH management is limited. The register-based study from Herniamed included 208 patients operated on for SIH with a one-year follow-up[[6]. Most patients had an ASA score of III/IV (71.6%) with morbid obesity in 36% of cases. The defect size was predominantly W1 (< 4 cm, 49%) and W2 (4–10 cm, 49%), underlying the complexity of managing SIH due to patient morbidities and large defect size.

Two literature reviews on the subject including only retrospective cohorts avoiding the calculation of any statistical result. Losanoff et al. [7] included 113 patients across 7 articles, reporting variable recurrence rates ranging from 0 to 33% after mesh repair and reaching 80% after suture repair. Chan et Al [2] analyzed 132 patients from 8 studies, five of which were included in the previous review. Recurrence rates ranged from 10 to 43%. The authors concluded that repair techniques, mesh types, overlap and approaches are not standardized for SIH management.

Suture or mesh repair

The first open SIH mesh repair was described in 1985 by Cohen et al. [15], using an entirely preperitoneal technique (Fig. 2). The use of a mesh for SIH repair reached consensus almost unanimously by the expert panel (97.1%). This aligned with Chan et Al.'s findings where recurrence rates were between 43 and 80% after suture repair and between 0 and 33% after mesh repair [2]. Another study involving 42 patients operated on for SIH with a double mesh technique (preperitoneal and onlay) reported only one recurrence after 25.8 months of follow-up [16].

Approach (MIS or open)

Both open and laparoscopic repairs are described in the literature, but robotic SIH repair has not yet been reported. The expert panel do not advise the IPOM technique for SIH repair (72.1%), despite the available literature reported some cases of laparoscopic IPOM repair [3, 6, 8, 9, 17].

In the Herniamed registry-based study, 208 patients were divided into 2 groups: 69 underwent laparoscopic SIH repair and 139 underwent open SIH repair. All laparoscopic procedures (69 patients) were IPOM with only 23.6% involving defect closure (IPOM+). Among the 139 open repairs, authors reported heterogenous techniques including sublay, IPOM, primary suture and onlay positions in 44%, 11%, 7% and 5% of patients, respectively. Defect closure was more frequent during open repair (45.8%; $p = 0.005$), noting 0.48% of component separation. The size of the SIH did not influence the surgical approach as 43.5% of W1 and 56.5% of ≥ W2 SIH underwent laparoscopic repair ($p = 0.46$ compared with open). There were no significant differences in recurrence rate, hospital stay and pain rate between the open and laparoscopic groups, although operative time was longer for laparoscopic repairs.

Losanoff et al. [7]. reported a 43–80% recurrence rates for sutures, 0–33% for open mesh surgery and between 0 and 30% for laparoscopic surgery. In another study comparing open (n = 20) vs. laparoscopic IPOM (n = 8) SIH repair, the size of the hernia did not influence the choice of approach ($p = 0.806$). No differences were found for acute complications, despite longer operative times in the open group and more recurrences in the laparoscopic group ($p = 0.031$) after 33 to 48 months of follow-up, probably because the defect was not closed during laparoscopic repair [17]. Generally, during laparoscopic SIH repairs, large defects were not closed (IPOM) [8, 17] and the mesh was partially covered by the falciform ligament [7, 8, 17].

In the present Delphi study, no consensus was reached on whether to use an open or MIS approach. For small W1 (< 4 cm) SIH, the panel agreed that both MIS and open approaches could be options (73.2%). This is consistent with the literature and with experts agreeing that regardless of approach, the main goal remains using a large mesh with > 5 cm overlap (79.7%).

Fixation

In the present Delphi study, consensus was reached that fixation is unnecessary if sufficient overlap is achieved for both extraperitoneal open and MIS SIH repair (78.6% and 73.2%, respectively). Most available studies describing laparoscopic

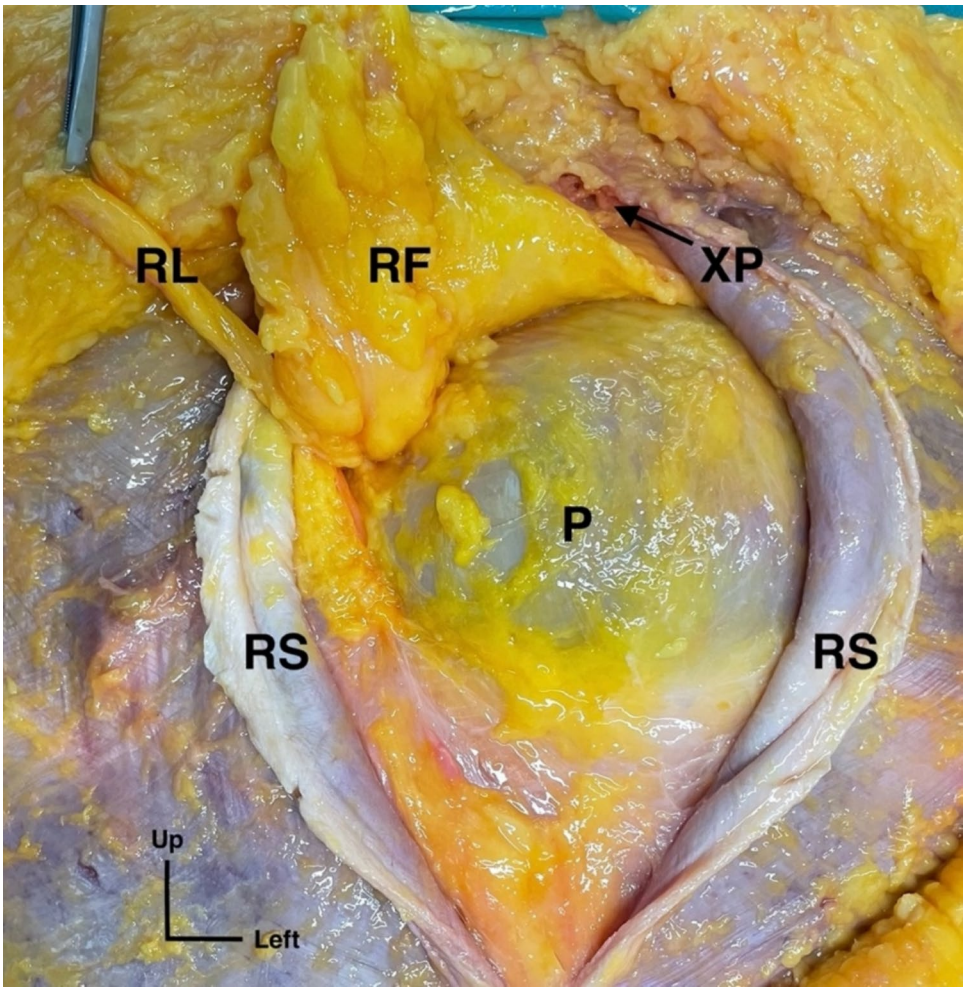

Fig. 2 Cadaveric view of the preperitoneal space of the subxiphoid area, showing the *P* peritoneum, the *RL* round ligament and the *RF* rhomboid fat reclined upwards, the *RS* retrorectus sheaths and the *XP* xiphoid process

IPOM repair [3, 6, 8, 9, 17], tackers were predominantly used for mesh fixations. One study reported using tackers only below the costal margin and sutures above to avoid pericardial injuries [8]. Concerning open surgery, some authors advocated no fixation for retrorectus SIH repair [6], while others suggested transfascial sutures [9, 15, 17]. When fixations were deemed necessary, the panel agreed to avoid self-fixating meshes or glue for open extraperitoneal repair (70.8% and 73.8%, respectively) and avoid tackers for MIS extraperitoneal repairs (92.3%).

Anatomical considerations, lateral and cranial dissections

General anatomical considerations

In the present Delphi study, the expert panel emphasized the need for sufficient mesh overlap as the primary goal of SIH repair, regardless of the surgical approach. However, achieving > 5 cm overlap cranially and laterally in the subxiphoid area can be challenging and the panel agreed that a solid knowledge of anatomy is required (75.4%).

The subxiphoid area is bordered cranially by the costal margin and rigid costoxiphoid ligaments with the xiphoid process as the apex and caudally by the linea alba, creating a rigid frame that prevents, under normal circumstances the laxity and mobility of tissues (Fig. 3).

Laterally, the proximal tendon of the rectus muscle inserts on the anterior surface of the 5th, 6th and 7th ribs and rib cartilages, extending to the costoxiphoid ligament and the xiphoid process [18]. The anterior and posterior rectus sheaths fuse and the rectus muscles diverge cranially and laterally thus explaining that the linea alba enlarges with a lack of muscular support (Fig. 4). This low elasticity may also explain why SIH are often large (mostly W2 [6]) and why median closure is sometimes nearly impossible as it complicates tissue mobilization and approximation during SIH repair. Moreover, the linea alba is a complex structure under tension where the aponeurotic fibers of the 3 lateral abdominal muscles join their contralateral counterpart, giving opposing forces stretching

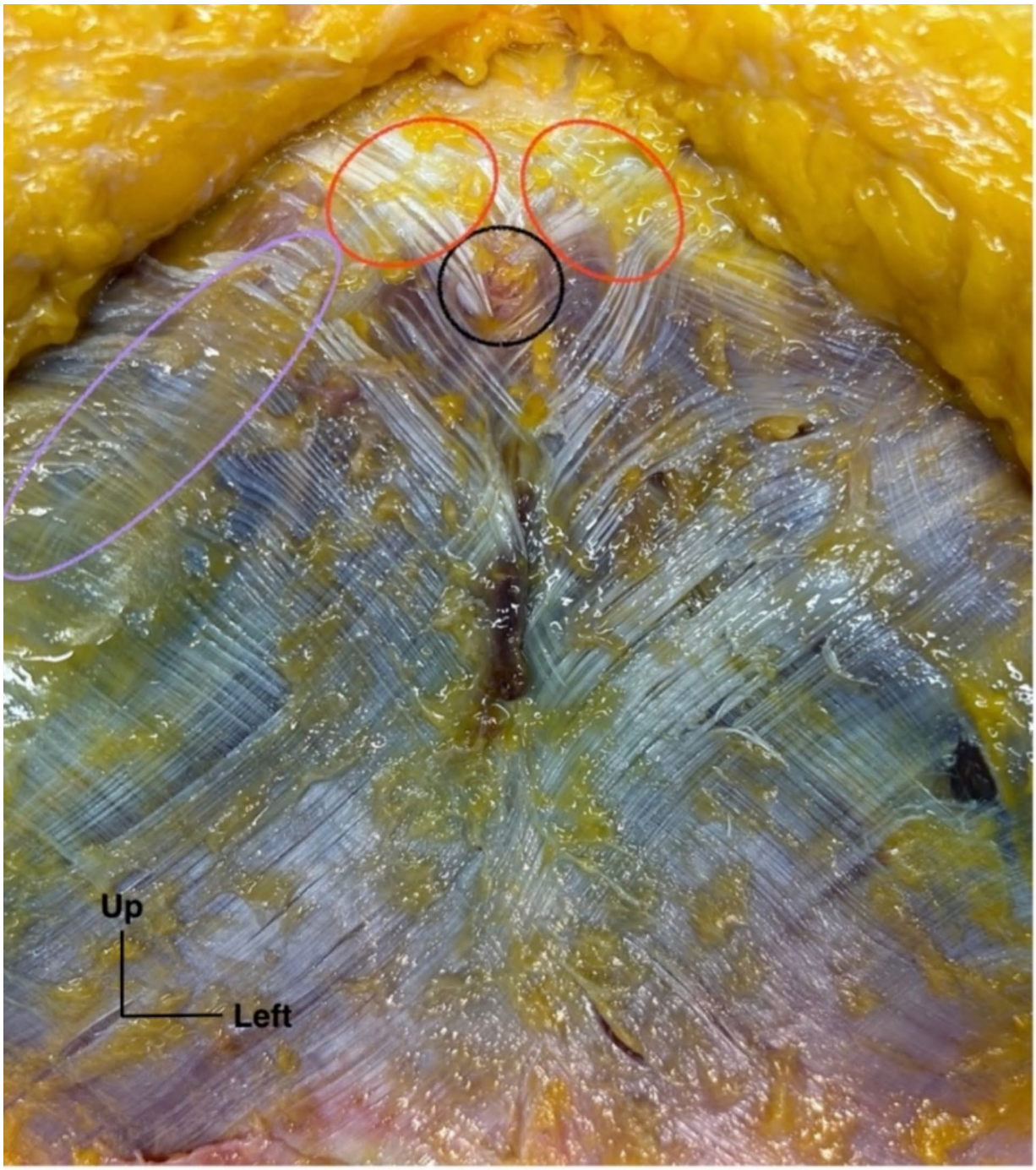

Fig. 3 Cadaveric front view of the subxiphoid area showing the fiber arrangements on the xiphoid process (black round), the costal margin (purple round) and the costo-xiphoïd ligament (red rounds) (color figure online)

the linea alba, thus increasing the risk of herniation in the subxiphoid area [19, 20] (Fig. 3). Particularly, the transverse abdominal muscle, whose cranial insertions behind the last ribs interdigitate with those of the diaphragm (pars costalis) represents, due to the transversal orientation of its fibers, the only antagonist muscle to the diaphragm.

Posteriorly, the xiphoid process gives insertions to the diaphragmatic fibers (pars sternalis) and therefore contributes to the respiration. During every Valsalva maneuvers (e.g., respiration, coughing, sneezing), descending diaphragmatic fibers induce ascending fascial traction on the

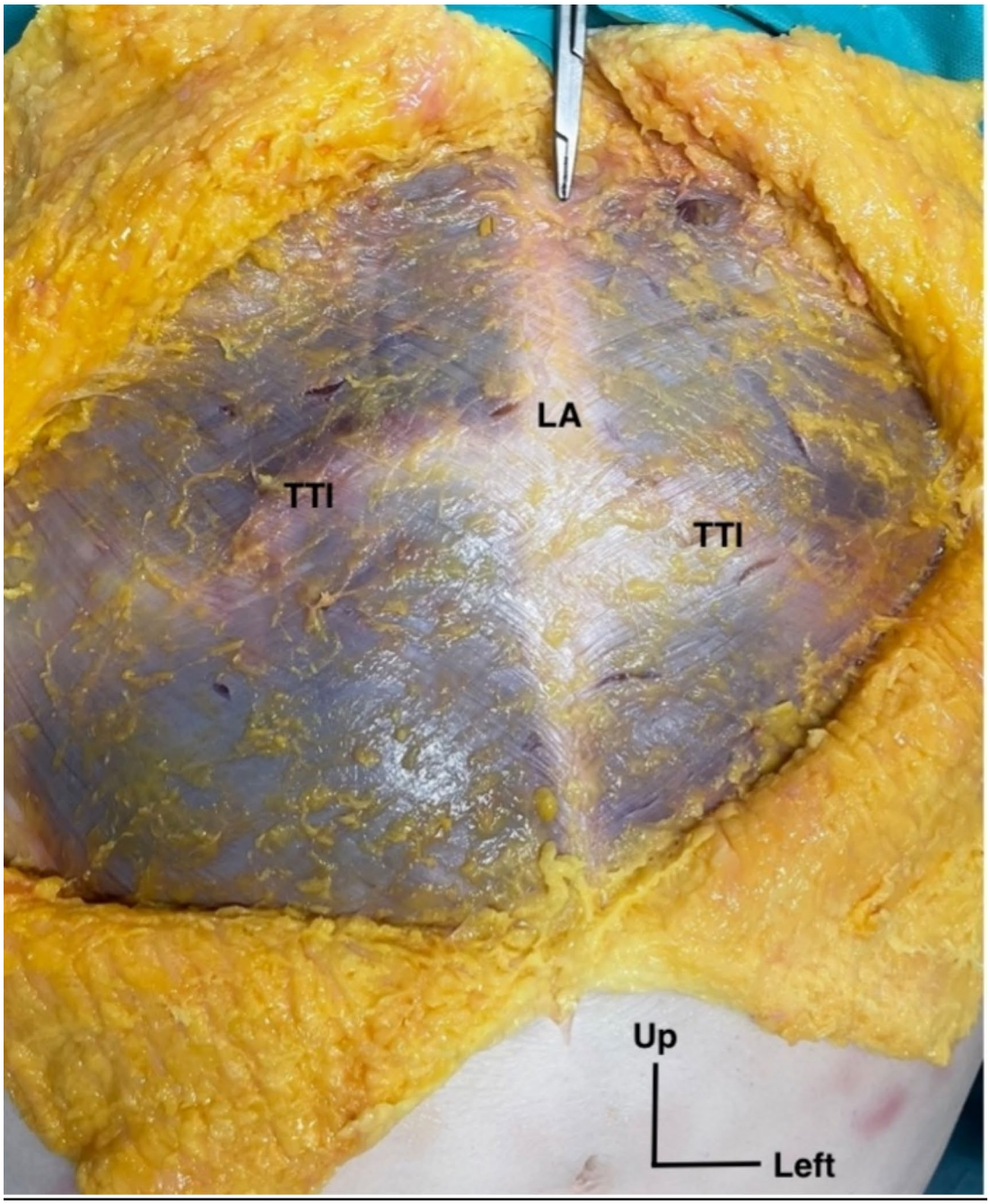

Fig. 4 Cadaveric view of the linea alba with the xiphoid process marked by a needle holder *TTI* transversal tendinous intersections, *LA* linea alba

subxiphoid area, increasing the risk of fascial dehiscence and making SIH repair even more difficult [21].

Behind the linea alba, the preperitoneal space may be surrounded by the 2 layers of transversalis fascia (Figs. 2 and 5). In the subxiphoid area, the fat is thicker and was first defined as the "fatty triangle" by Conze and Schumpelick in 2004 [22]. The entire preperitoneal fat was thoroughly described in 2022 by Urena et al. [23] and the authors reported that the preperitoneal fat has a trident shape, its cranial part resembling a rhomboid, including the fatty triangle. On a cadaver study, Conze et al. [13] reported in 2005 the precise anatomy of this fatty area, located behind the linea alba, extending behind the xiphoid process until the retrosternal space and attaching the sternum and the pericardium (Figs. 2 and 5). Thus, we can consider that the transversalis fascia in this location may have 2 layers: one deep fascia between the rhomboid fat

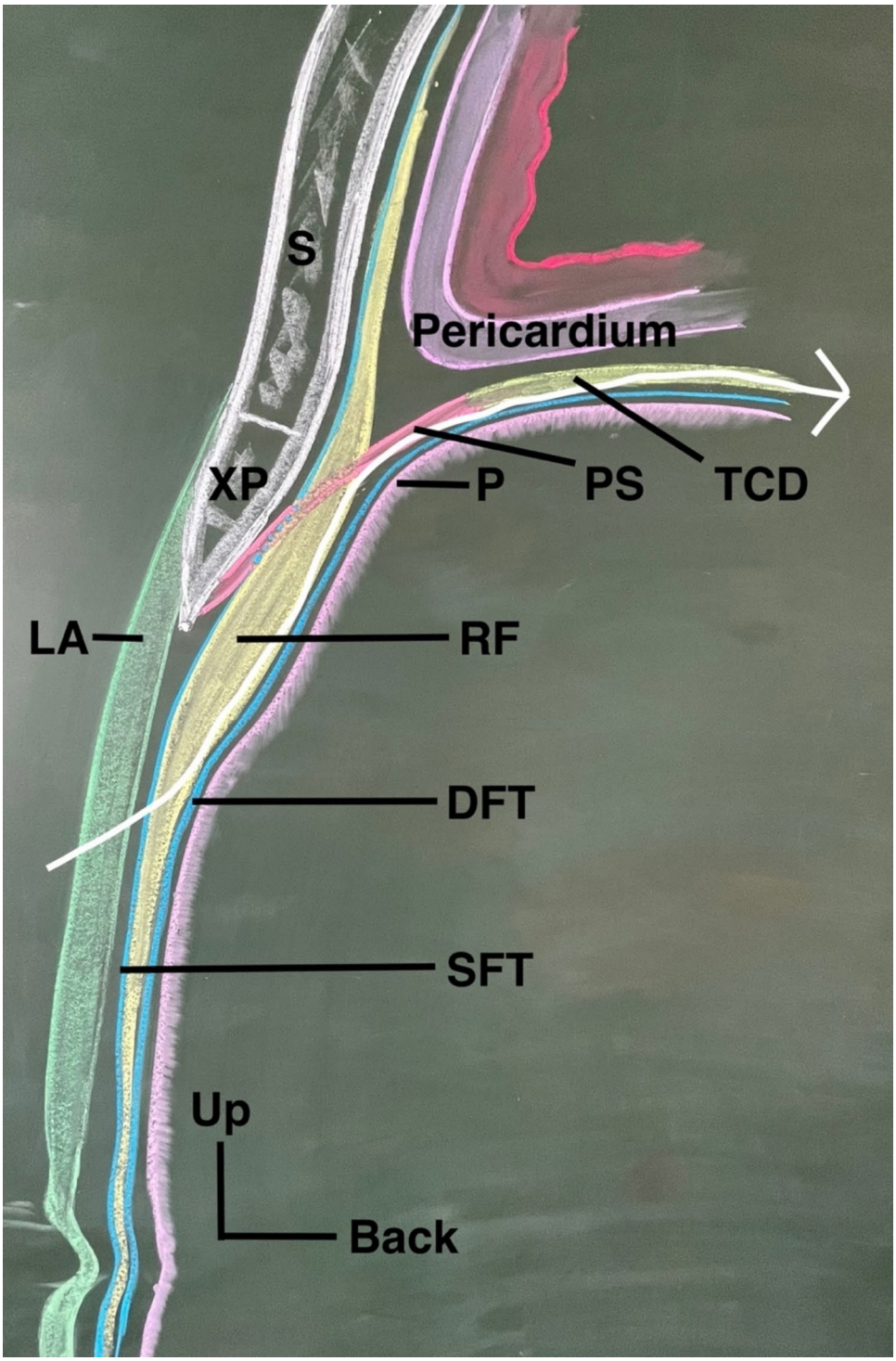

Fig. 5 Median sagittal view of the subxiphoid area through the xiphoid process *S* sternum, *XP* xiphoid process, *LA* linea alba, *TCD* central tendon of diaphragm, *PS* pars sternalis, *P* peritoneum, *RF* rhomboid fat, *DFT* deep transversalis fascia, *SFT* superficial transversalis fascia. The white arrow shows the cranial extension from the preperitoneal space between the deep transversalis fascia and the rhomboid fat to the space between the diaphragmatic fascia and the diaphragm

and the peritoneum, prolonged cranially by the diaphragmatic fascia and one superficial fascia, between the linea alba and the rhomboid fat that continues to the anterior mediastinum between the fiber of the pars sternalis of the diaphragm forming the endothoracic fascia behind the sternum (Fig. 5).

Lateral extension

On one hand, the expert panel agreed that enough overlap of > 5 cm represents the main goal of SIH repair (73.2%). One the other hand, they also agreed that the extraperitoneal techniques are the best repair (72.1%), even for MIS < 4 cm (W1) approach (75.4% agreed for E-TEP and/

or ventral TAPP techniques, i.e. extraperitoneal). These statements are consistent with another consensus stating that the best mesh position is retro rectus (in the middle) and pre-peritoneal laterally (after a TAR) for any repair (78.5%) and for ≥ W2 (≥ 4 cm) open SIH repair (86.2%). Nevertheless, 70.8% of the panel disagreed that the ideal mesh position for open ≥ 4 cm (≥ W2) SIH repair would be totally pre-peritoneal, while it represents the second possibility to insert the mesh in an extraperitoneal position with large overlap. In fact, achieving enough lateral overlap in an extraperitoneal position implies for surgeon to master the anatomy of the extraperitoneal layers which seems difficult in this area (75.4% of agreement).

To ensure enough lateral overlap, first option would be a totally preperitoneal dissection:

- In the middle, between the deep transversalis fascia and the center of the rhomboid fat (Figs. 5 and 6).
- Laterally, behind the rectus muscle, between the deep transversalis fascia and the lateral edge of the rhomboid fat (Fig. 7).

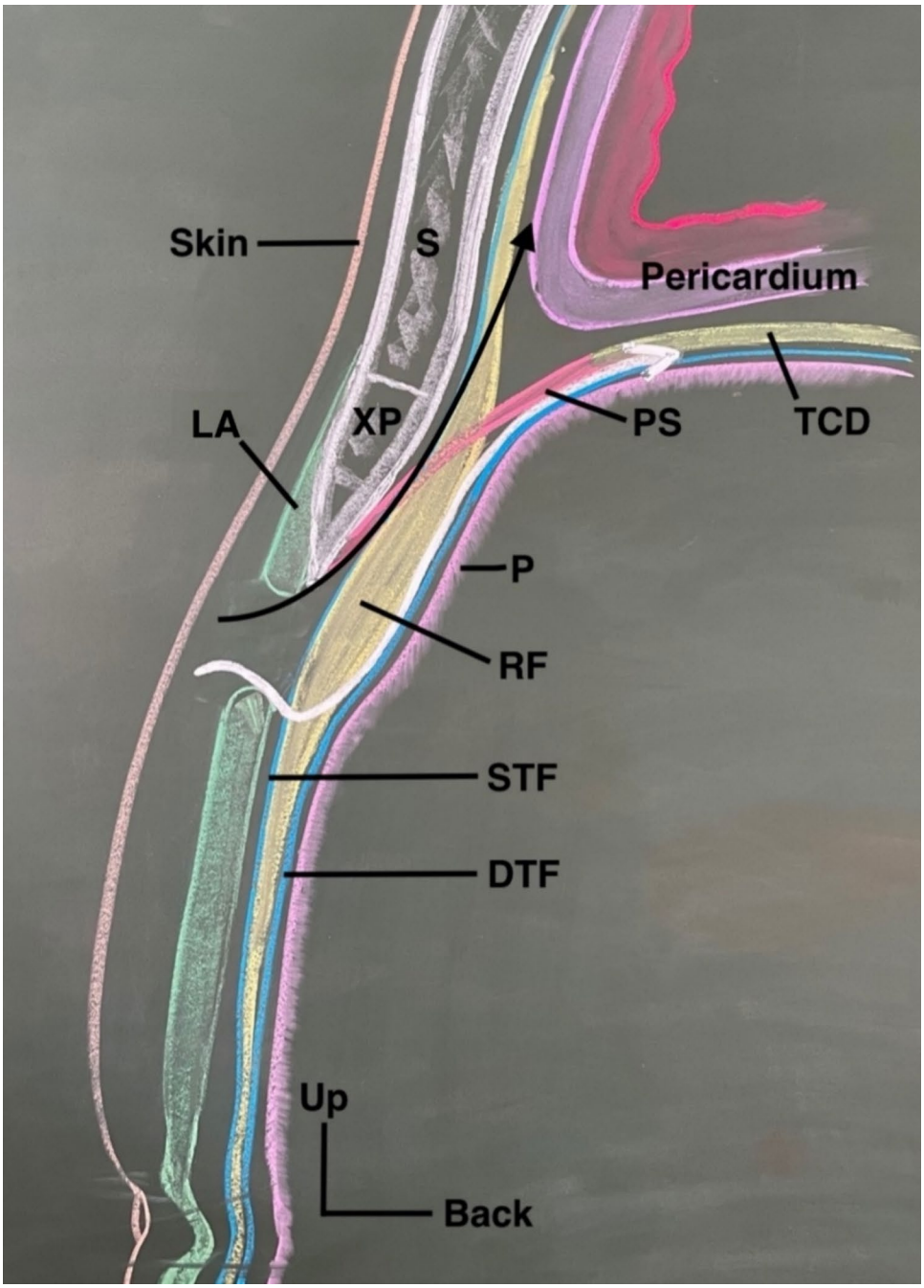

Fig. 6 Median sagittal view showing the open preperitoneal repair by an open approach *S*: sternum, *XP* xiphoid process, *LA* linea alba, *TCD* central tendon of diaphragm, *PS* pars sternalis, *P* peritoneum, *RF* rhomboid fat, *STF* superficial transversalis fascia, *DTF* deep transversalis fascia. The white arrow shows the cranial extension from the preperitoneal space (plane between the deep transversalis fascia and the rhomboid fat) to the space between the diaphragmatic fascia and the diaphragm after reclining the rhomboid fat. The black arrow shows the dissection to the plane in front of the rhomboid fat leading to the endothoracic fascia (wrong plane with a risk of cutting the insertions of the diaphragm and approaching the pericardium)

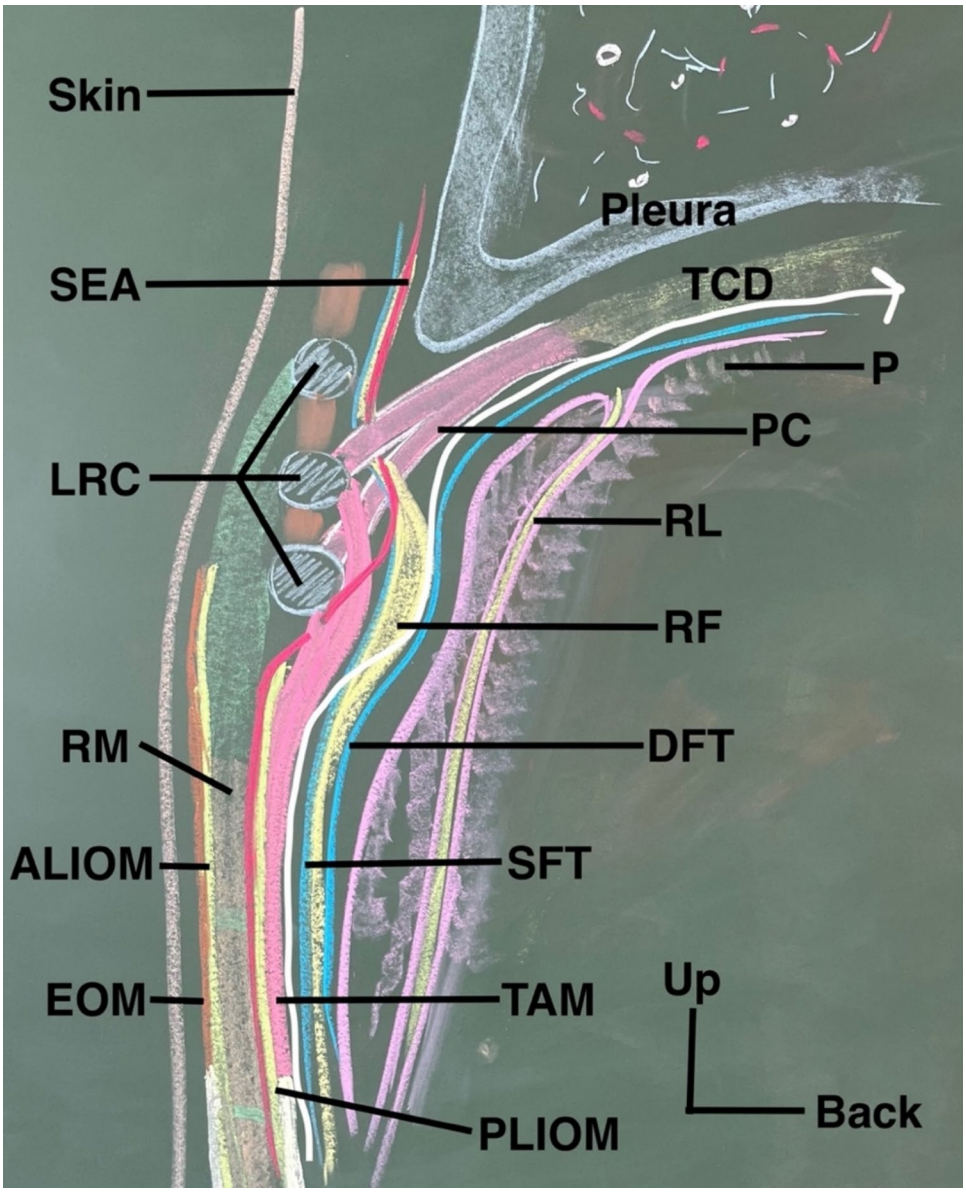

Fig. 7 Paramedian sagittal view of the subxiphoid area through the last rib *SEA* superior epigastric artery, *TAM* transversus abdominis muscle, RM rectus muscle, *TCD* central tendon of diaphragm, *PC* pars costalis, *RL* round ligament, *P* peritoneum, *RF* rhomboid fat, *DTF* deep transversalis fascia, *SFT* superficial transversalis fascia, *LRC* last rib cartilage, *ALIOM* anterior lamina of the internal oblique muscle, *EOM* external oblique muscle, *TAM* transversus abdominis muscle, *PLIOM* posterior lamina of the internal oblique muscle. The anterior rectus sheath = EOM + ALIOM. The posterior rectus sheath = TAM + PLIOM. The white arrow shows the cranial extension from the preperitoneal space (plane between the deep transversalis fascia and the rhomboid fat) to the space between the diaphragmatic fascia and the diaphragm after reclining the rhomboid fat (color figure online)

This option implies a solid knowledge of the position of the rhomboid fat as previously described.

Second option would be a retrorectus repair:

- Medially in the retrorectus space (Fig. 5).
- Laterally between the transversalis fascia and the transversus abdominis muscle (Fig. 8).

Between both, a TAR is necessary (Figs. 8 and 9).

For this second option, the rhomboid fat is not involved and the difficulty comes from the lateral extension: a proper modified Madrid TAR sparing the intercostal nerves from T7 to T9 should be performed properly [24, 25].

Cranial extension

The cranial extension of the overlap may be the most challenging step for SIH repair, due to bony structures, diaphragmatic and rectus muscle insertions. The panel agreed that the dissection behind the xiphoid process (73.8% of consensus) until the central tendon of the diaphragm (84.6%) allows enough cranial overlap. Moreover, they agreed that reaching the central tendon of the diaphragm represents an indicator of quality of cranial dissection (80.4% of the panel) (Fig. 10).

In the midline, the linea alba and anterior rectus sheath inserts in front of the xyphoid process and the last rib cartilages. Behind, only the rhomboid fat, surrounded by the

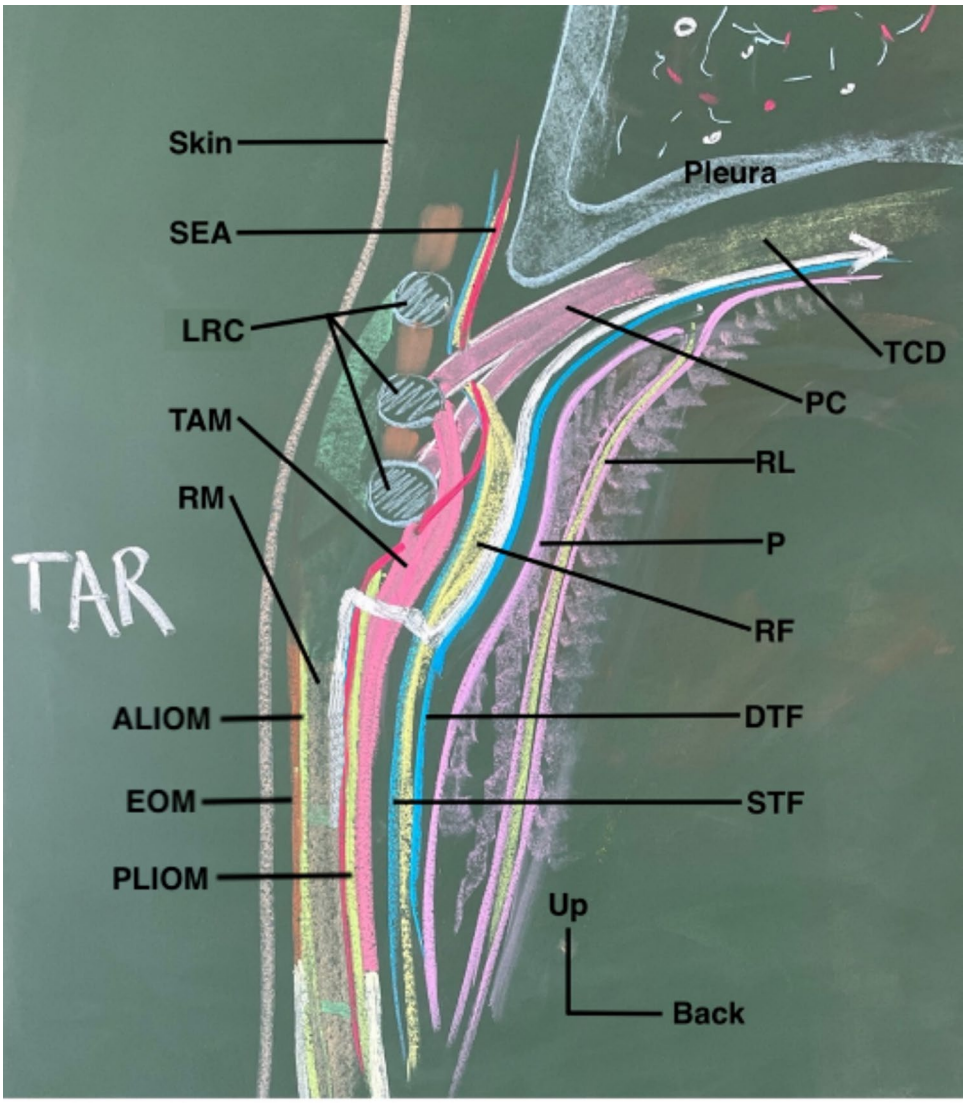

Fig. 8 Paramedian sagittal view showing with a white arrow a retrorectus repair with preperitoneal cranial extension, by an open approach *SEA* superficial epigastric artery, *TAM* transversus abdominis muscle, *RM* rectus muscle, *TCD* central tendon of diaphragm, *PC* pars costalis, *RL* round ligament, *P* peritoneum, *RF* rhomboid fat, *DTF* deep transversalis fascia, *STF* superficial transversalis fascia, *LRC* last rib cartilage, *ALIOM* anterior lamina of the internal oblique muscle, *EOM* external oblique muscle, *PLIOM* posterior lamina of the internal oblique muscle. The anterior rectus sheath = EOM + ALIOM. The posterior rectus sheath = TAM + PLIOM

transversalis fascia, can be found (Fig. 5). Laterally, the posterior rectus sheath comes from the posterior lamina of the internal oblique muscle and the aponeurosis of the transversus abdominis muscle, inserting below and behind the last ribs, respectively [20](Fig. 7). Consequently, the retrorectus compartment ends, cranially, between the rectus fibers and the last rib cartilage. The internal oblique and transversus abdominis muscles act as an anatomical barrier to extend the dissection [13].

Consequently, in case of preperitoneal repair, accessing to the central tendon of the diaphragm (Fig. 10) implies dissecting between the deep transversalis fascia and the rhomboid fat, then dissecting between the diaphragm and the diaphragmatic fascia until the central tendon (Figs. 5 and 6).

In case of retrorectus repair, the posterior rectus sheath must be incised horizontally 3–4 cm below the xyphoid process, then entering the plane between the deep transversalis fascia and the rhomboid fat (Fig. 9). Just lateral to this section, the TAR should be done as previously described. Then, the dissection continues between the diaphragm and the diaphragmatic fascia until the central tendon (Fig. 8). This technical procedure appeared clear for the panel experts since they agreed that posterior sheath must be cut to ensure enough superior overlap for the mesh (78.5%). Stoppa already described partially this procedure years ago and advocated for the incision of the transversus abdominis muscle parallel to the costal border at 2 cm [26]. Conze and Schumpelick suggested cutting the posterior rectus sheath from the costal margin to access the retroxiphoid space [13].

The risk of this dissection is to enter the plane in front of the rhomboid fat (superficial transversalis fascia), just against the posterior side of the xiphoid process, cutting the insertions of the diaphragm, following the endothoracic fascia in the retrosternal area and approaching the pericardium (Fig. 6). If the mesh end just behind the xiphoid, this

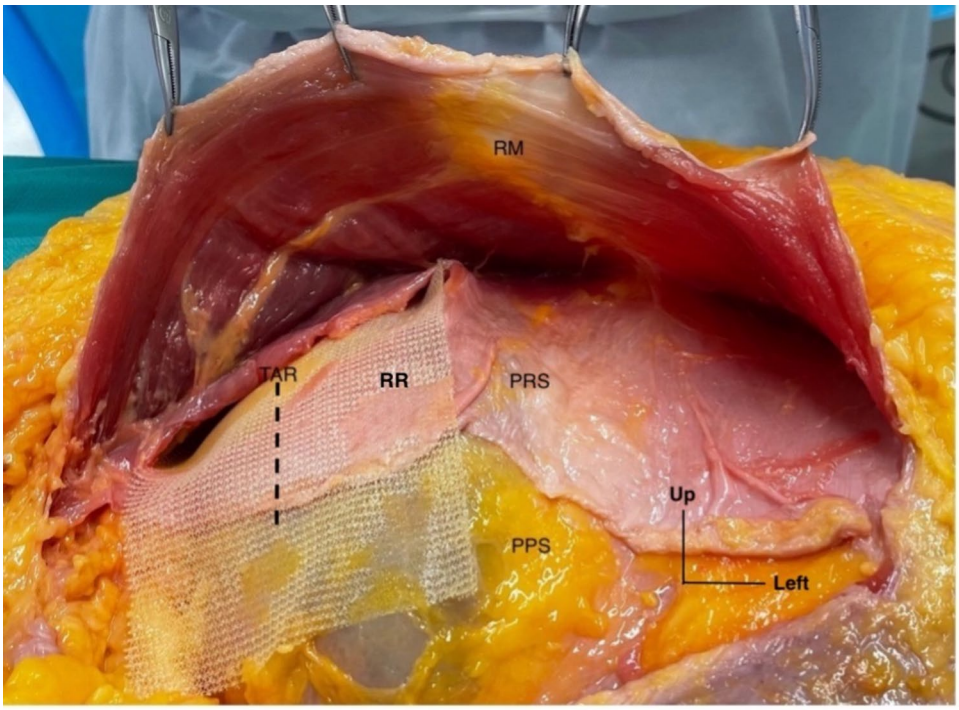

Fig. 9 Lateral cadaveric view showing the lateral extension from the *RR* retrorectus space to the lateral *PPS* preperitoneal space after a TAR by cutting the *PRS* posterior rectus sheath horizontaly (dotted line). *RM* rectus muscle

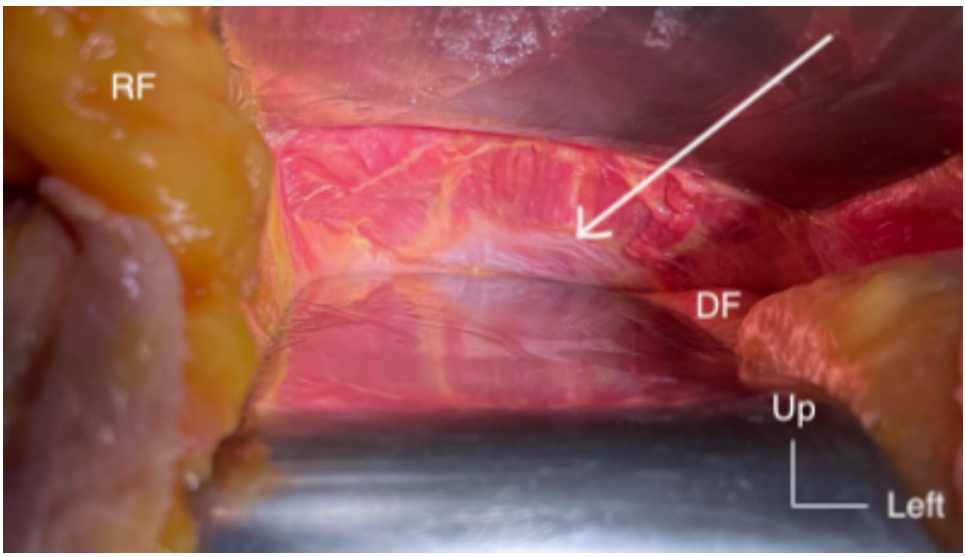

Fig. 10 Cadaveric view of the cranial dissection until the central tendon of diaphragm (white arrow), between the *RF* rhomboid fat avec the *DF* diaphragmatic fascia (color figure online)

dissection leads to insufficient cranial overlap and has been reported previously [6, 7, 13] (Fig. 11).

Midline closure

The fibrous structures and the lack of lateral tissue for medialization may lead to high difficulties for the midline closure, as pointed out by the expert panel (81.5%). However, the necessity of midline closure during SIH repair reached consensus (90.8%).

Among the procedures helping to close the midline usually described, the panel excluded the interest of anterior component separation (76.9%), peritoneal flap (73.8%) and intraoperative fascial traction (71%). According to the panel, performing a TAR may be an option to close the defect but with limited impact (75%) and should not be performed systematically (81.5%). Of note, Botulinum toxin was not studied in this Delphi.

We completely agree with the panel since the rectus muscles laterally insert, in this area, on the last ribs and not on the lateral muscles. Therefore, component separations and

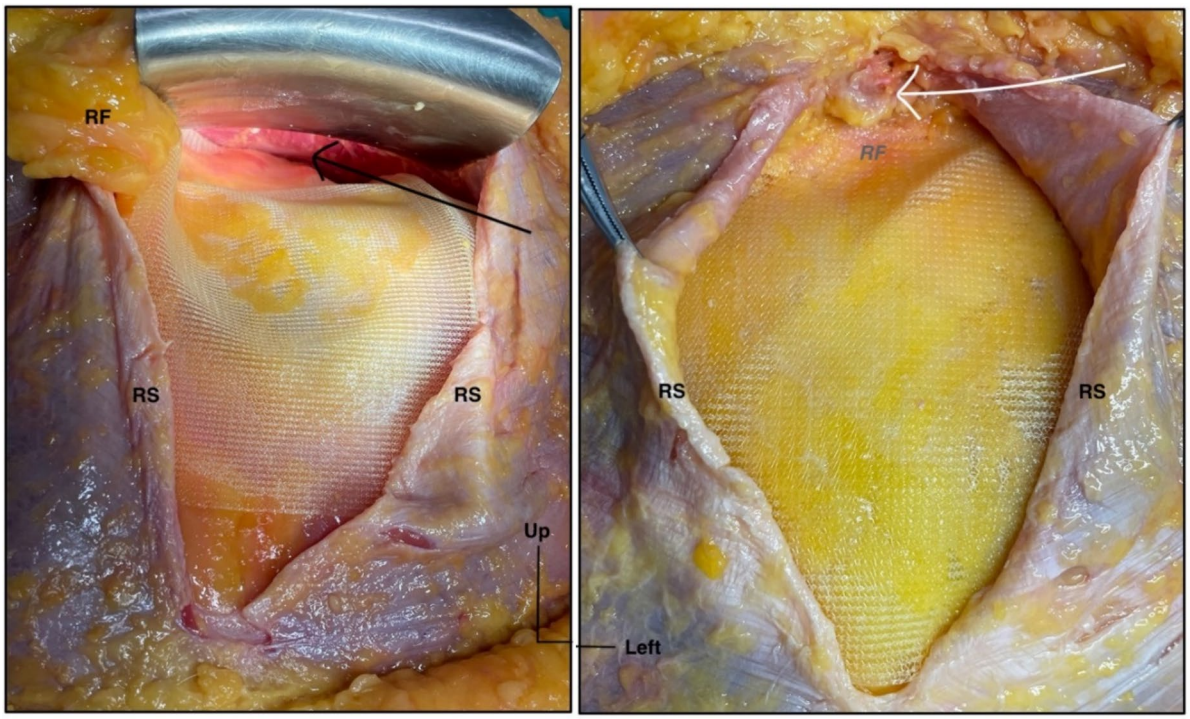

Fig. 11 Cadaveric view of the correct position of the mesh under the *RF* rhomboid fat until the central tendon of diaphragm (black arrow) allowing enough overlap (left) vs. superficial position of the mesh behind the xiphoid process in front of the *RF* rhomboid fat leading to insufficient cranial overlap (right)

fascial traction will lead to very few effects. A TAR can be performed but we argue that this procedure will allow more overlap than medialization. Anyway, a TAR is necessary in case of retrorectus repair. We also agree with the panel that bridging with an extraperitoneal mesh may be the only solution in case of non-closure (83.1%). We argue that the section of the proximal insertions of the rectus muscle from the ribs, similarly to relaxing incisions [27], could help sliding the rectus muscles medially in some cases. Moreover, an onlay repair may be another solution at a last resort as previously described [6, 16, 27].

Items without consensus

Concerning preoperative imaging, all proposals (thoracoabdominal CT scan, abdominal CT scan, RMI with or without Valsalva maneuver) didn't reach consensus during the 3 rounds although a CT-scan is recommended for incisional hernias [28]. The specific type of CT was not consensual probably due to different access to imaging or the CT field of view across countries.

Concerning the surgical technique according to the sizes W1 and W2, the panel sometimes gave contradictory answers. For example, an open retrorectus repair with TAR for W2 SIH received agreement but not a totally preperitoneal repair. Further, 75.4% of the experts agreed that the ideal approach in case of MIS for W1 hernias would be E-TEP and/or ventral TAPP but the proposal of retrorectus repair with TAR or totally preperitoneal repair reached 58.9% and 55.4%. of agreement, respectively. Again, the panel gave more consideration to the mesh overlap and the defect closure than to the type of approach.

The Delphi was closed after round 3 since the trio expert considered that no consensus would have been reached for these items, regardless of how they could have been written and the lack of literature on the subject.

Limits of the work

The strength of the present study probably comes from the gathering of a lot of expert surgeons from different countries, with different point of view and habit. It probably provides the sole strength to this paper.

Nevertheless, limitations of this study come from the nature of a Delphi consensus, established from expert opinion, with no high-quality data. Some stronger processes exist, like ACCORD checklist, but the present study did not aim at reporting any recommendation. This limitation may add bias to our conclusions, although we tried to report a consensus as honest as possible.

Conclusion

The present Delphi consensus helps strengthen the definition of SIH: it is a defect where the M1 part is the most challenging or the most representative part. A mesh should be used according to the experts. A consensus was reached for an extra-peritoneal repair (totally preperitoneal or retro-rectus medially and preperitoneal laterally after a TAR) with an overlap of more than 5 cm, without fixation. In MIS, E-TEP and/or ventral TAPP should be performed according to the panel. Bridging repair may be a solution in case of non-closure after a proper TAR. According to the panel, ensuring superior overlap implies dissecting behind the xiphoid process and the rhomboid fat, until the central tendon of diaphragm, after cutting horizontally the posterior rectus sheath.

These statements are not recommendations, but expert consensus. This work provides a basis for future studies, including acute anatomical description of the subxiphoid region and prospective and/or register based studies evaluating indications and types of SIH repair. So far, SIH remains an unknown challenge and 90.8% of experts believed that SIH $\geq$ W2 should be -referred to an expert parietal surgery center.

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Author contributions All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Alix Donadieu, Sarfaraz Jalil Baig and Yohann Renard. The first draft of the manuscript was written by Alix Donadieu and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data Availability All data, materials and software application comply with field standards.

Declarations

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

Ethical approval The present study includes patients operated on using routine and local standards. The techniques reported in the present article were locally protocolized for a long time and followed the current state-of-the-science of incisional hernia management.

Human and animal rights This article does not contain any studies with human participants or animals performed by any of the authors.

Consent to participate The folders of all patients were retrospectively analyzed. All patients received adequate information and gave their written informed consent to be operated on following our local protocol.

Consent for publication Informed consent was obtained from all individual participants included in the study.

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