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Components Separation Techniques in Abdominal Wall Surgery

Issue Editors

René Fortelny
Sigmund Freud University
Vienna, Austria

Lars Nannestad Jørgensen
Bispebjerg Hospital,
Denmark

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Components Separation Techniques in Abdominal Wall Surgery

Components Separation Techniques in Abdominal Wall Surgery (anterior, posterior, combined, minimally invasive)

Component separation is now an essential part of modern abdominal wall surgery for ventral and incisional hernias. The aim of this additional technique is the complete restoration of the midline, which at the same time should guarantee a recovered core stability at the final stage. The techniques for this purpose are diverse and are now applied open, minimally invasive or in hybrid techniques, depending on the primary approach chosen. This Special Issue is intended to provide an overview of the various release techniques, as well as specifically the individual methods with the most important steps and results.

The aim of this Special Issue is to compare the different techniques and to present the advantages and disadvantages, or the potential complications. Another aspect of this edition is to create a potential algorithm for the specific application based on the anatomical preconditions.

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Editorial: Components Separation Techniques in Abdominal Wall Surgery

René H. Fortelny[1] and Lars Nannestad Jørgensen[2]*

[1]*General Surgery, Sigmund Freud Private University Vienna, Vienna, Austria,* [2]*Digestive Disease Center, Bispebjerg Hospital, University of Copenhagen, Copenhagen, Denmark*

Keywords: abdominal wall reconstruction, complex ventral and incisional hernias, component separation techniques, hernia surgery, open anterior and posterior approaches

Editorial on the Special Issue

Components Separation Techniques in Abdominal Wall Surgery

Component separation techniques (CST) have become an essential part of abdominal wall reconstruction, providing reliable myofascial advancement for complex ventral and incisional hernias. The primary objective of CST is restoration of the midline and re-establishment of functional core stability. The available CST methods now include open anterior and posterior approaches, minimally invasive and endoscopic variants, hybrid procedures, and combined releases tailored to anatomical characteristics.

Since the first description of the anterior CST by Albanese [1] and its popularization by Ramirez et al. [2], several refinements have been made. Anterior CST enables medialization through external oblique release but requires extensive subcutaneous dissection, resulting in increased wound morbidity. This limitation promoted the transition toward posterior CST, which preserves perforators, minimizes soft-tissue trauma, and allows for retromuscular mesh placement—a strategy associated with improved long-term durability.

Posterior CST was further advanced with the introduction of transversus abdominis release (TAR)by Novitsky et al [3]. TAR facilitates wide lateral release and creation of a continuous retromuscular plane suitable for large meshes. It has become the preferred method for extensive defects, recurrent hernias, and loss-of-domain cases, demonstrating low recurrence rates between depending on complexity [4].

Endoscopic anterior CST represents an important minimally invasive alternative [5]. By preserving perforating vessels and avoiding wide subcutaneous flaps, it reduces wound morbidity compared with the open anterior approach. However, its medialization potential remains more limited, and the learning curve is considerable. Additionally, patient selection is more restricted, as severe scarring, prior lateral releases, or large defects may limit its applicability. Nevertheless, when applied appropriately, endoscopic ACS offers a valuable option within the CST armamentarium.

A further adjunct increasingly used in complex cases is intraoperative fascial traction [6]. Various devices and traction protocols have been developed to promote progressive medialization during surgery, particularly in large or rigid defects. Fascial traction can be combined with posterior CST or TAR to facilitate midline closure, reduce tension, and avoid excessive lateral releases. Early data suggest promising reductions in defect tension, although standardized indications and protocols are still lacking.

Despite the expanding CST toolbox, generating a universal treatment algorithm remains difficult. Differences in defect morphology, tissue quality, prior operative history, patient comorbidities, and

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***Correspondence**
René H. Fortelny,
rene.fortelny@mail.sfu.ac.at

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surgeon expertise create considerable variability between cases. While attempts have been made to classify defects and match them to specific CST techniques, the heterogeneity of abdominal wall pathology and the rapid evolution of new methods limit the feasibility of a strictly applied algorithm. Instead, individualized treatment planning based on anatomical, functional, and technical considerations remains essential.

Minimally invasive and robotic techniques continue to broaden the reach of CST. Robotic TAR (rTAR) has demonstrated advantages including enhanced visualization, improved ergonomics, and reduced postoperative morbidity [7]. Recurrence outcomes appear comparable to open TAR, although access to robotic platforms and procedural costs remain limiting factors. Structured training pathways are required as these technologies gain prominence.

Optimal outcomes require thorough patient optimization. Obesity, malnutrition, diabetes, smoking, and sarcopenia significantly increase postoperative risk. Prehabilitation—including nutritional support, metabolic control, and physical conditioning—is increasingly recognized as essential. Adjunctive strategies such as botulinum toxin A injections and progressive pneumoperitoneum aid in loss-of-domain scenarios by reducing closure tension and improving abdominal compliance [8].

Mesh selection remains a critical element of CST-based reconstruction. Permanent synthetic mesh used in the retromuscular plane provides durable reinforcement in clean settings, while biologic and biosynthetic meshes may be considered for contaminated or high-risk fields. TAR's ability to create a large, vascularized retromuscular space promotes excellent mesh integration and long-term stability.

Challenges persist, including variability in surgical technique and inconsistency in terminology, which complicate comparison across published studies. Functional outcomes—such as abdominal wall strength, core stability, and health-related quality of life—remain underreported relative to recurrence. Standardized reporting frameworks and multicenter registries will be essential to refine indications and compare CST techniques.

Future developments in CST will likely benefit from advanced imaging, quantitative CT-based reconstruction planning, artificial intelligence–assisted prediction models, and biomaterials such as patient-specific 3D-printed meshes. Integration of these innovations into clinical practice must be guided by robust long-term evidence.

In summary, CST has matured into a versatile reconstructive strategy for complex abdominal wall defects. Posterior CST and TAR remain the cornerstone of modern reconstruction, while minimally invasive and endoscopic techniques offer alternative approaches in selected cases. Adjuncts such as intraoperative fascial traction further expand the reconstructive armamentarium. Continued innovation, improved standardization, and emphasis on functional outcomes will be essential for further advancement of the field.

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CASE REPORT
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Case Report: Combined Intercostal-Transdiaphragmatic-Abdominal Wall Hernia

P. Martínez-López[1,2]*, *M. Verdaguer-Tremolosa*[1,2], *V. Rodrigues-Gonçalves*[1,2], *A. Martín-Del-Rey*[3] *and M. López-Cano*[1,2]*

[1]Department of Surgery, UD of Medicine of Vall d'Hebron, Universitat Autònoma de Barcelona, Barcelona, Spain, [2]Abdominal Wall Surgery Unit, General and Digestive Surgery Department, Hospital Universitari Vall d'Hebrón, Barcelona, Spain, [3]General and Digestive Surgery Department, Hospital Universitari Vall d'Hebrón, Barcelona, Spain

Aim: To present a rare and complex case of a spontaneous intercostal, transdiaphragmatic and abdominal wall hernia in an elderly male with a history of chronic obstructive pulmonary disease (COPD).

Methods: According to the CARE checklist, we describe a rare case of intercostal, transdiaphragmatic and abdominal wall hernia after an episode of severe coughing.

Results: A 72-year-old male presented with nausea, dyspnea, and progressive left thoracic and abdominal swelling, along with a history of severe cough and spontaneous hematoma in the same regions. A CT scan revealed an intercostal hernia between the 8th and 9th ribs, with transdiaphragmatic extension and involvement of the lateral abdominal wall, containing most of the stomach, transverse colon, splenic flexure, descending colon, and small intestine. An elective left thoraco-abdominal open surgery was performed, including preperitoneal hernioplasty with dual mesh placement and repair of the diaphragmatic and costal defect.

Conclusion: Such cases are scarcely reported in the literature. This case highlights the importance of considering complex hernia in patients with severe COPD and the importance of early treatment along with a multidisciplinary surgical approach.

Keywords: intercostal hernia, transdiaphragmatic hernia, abdominal wall hernia, chronic obstructive pulmonary disease, cough

***Correspondence**
P. Martínez-López,
pilarmartinezlopez3@gmail.com
M. López-Cano,
mlpezcano@gmail.com

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INTRODUCTION

Intercostal, transdiaphragmatic, and abdominal wall hernias are exceptionally rare due to the extensive nature of the hernia and the involvement of multiple compartments, including thoracic and abdominal cavities [1]. When the abdominal viscera gain entry to the intercostal space through an associated diaphragmatic defect, the term of transdiaphragmatic intercostal hernia is usually employed, where as if no diaphragmatic abnormality is present, the term abdominal intercostal hernia (AIH) is used [2, 3]. These types of hernia are almost always located inferiorly to the ninth rib and are predominantly found on the left thoracic side [3, 4]. They usually occur after trauma, but less frequently, increased intrathoracic pressure during episodes of severe coughing can cause a hernia, although this is rarely reported [2].

CASE DESCRIPTION

We report the case of a 72-year-old male, former smoker, with a medical history of arterial hypertension, diabetes mellitus, and chronic obstructive pulmonary disease (COPD). He was hospitalized in December 2023 for community-acquired pneumonia.

In February and March 2024, the patient presented to the emergency department with symptoms including nausea, dyspnea, and progressively increasing left-sided thoracic and abdominal swelling. He reported experiencing a severe cough following the pneumonia episode, which was soon followed by the spontaneous appearance of a hematoma on the left hemithorax and hemiabdomen. On physical examination, significant left-sided thoracic and abdominal swelling was observed, along with clinical signs suggestive of a partially reducible hernia (**Figure 1**).

A computed tomography (CT) scan revealed an intercostal hernia between the eighth and ninth ribs, extending transdiaphragmatically and involving the left lateral abdominal wall. The hernia sac contained the majority of the stomach, colon and loops of small bowel (**Figure 1**). The patient underwent preoperative optimization, including prehabilitation focused on weight loss and control of COPD to minimize the risk of hernia exacerbation.

In April 2024, the patient underwent an elective open thoracoabdominal hernia repair. Intraoperative findings included a 9 × 9 cm defect in the internal oblique and transversus abdominis muscles, with costal cartilage disinsertion between the 8th and 9th ribs, as well as an 8 cm diaphragmatic defect. The hernia sac extended into the left abdominal wall, intrathoracic, and intercostal regions.

A preperitoneal hernioplasty was performed using Bio-A and polypropylene mesh to reinforce the abdominal wall (**Figure 2**). The diaphragmatic defect was repaired and reinforced with a Synecor mesh (**Figure 3**). Thoracic surgeons closed the intercostal space and placed a thoracic drain, ensuring closure of the communication between the preperitoneal lateral space and the thoracic cavity.

During hospitalization, an episode of renal insufficiency exacerbation occurred, which was successfully managed with targeted therapy. He was discharged after 11 days with no further complications.

At 6-month follow-up, the only significant finding was a minor subcutaneous seroma at the site of the thoracic incision. There were no reports of abdominal or thoracic discomfort, dyspnea, or other complications. The patient continued respiratory rehabilitation, showing effective management of his COPD.

DISCUSSION

This is a rare pathology in clinical practice, and much of the existing literature consists of case reports. Systematic reviews on this topic highlight the absence of a standardized classification system to guide the management of the various types of hernias, given the diversity in their presentations [5, 6]. These hernias are typically classified as either acquired or spontaneous [1–3, 7, 8]. Acquired hernias are generally secondary to major trauma, such as penetrating injuries, falls, or crush injuries [5], as well as to minor trauma, such as a sudden increase in thoracic pressure caused by severe coughing, childbirth, physical exertion, or vomiting [1–4, 7, 9, 10]. However, in spontaneous cases, the literature reveals that patients often report chronic coughing related to smoking, COPD, obesity, advanced age, or collagenopathies [1, 2, 7, 11, 12]. It remains debatable whether these cases are truly spontaneous or result from repeated minor trauma over time. In our view, this type of hernia should always be considered acquired, either through an acute traumatic event or through chronic, repeated minor trauma from increases in thoraco-abdominal pressure.

The lack of consistency in the literature complicates the identification and management of these cases. In 1978, Le Neel

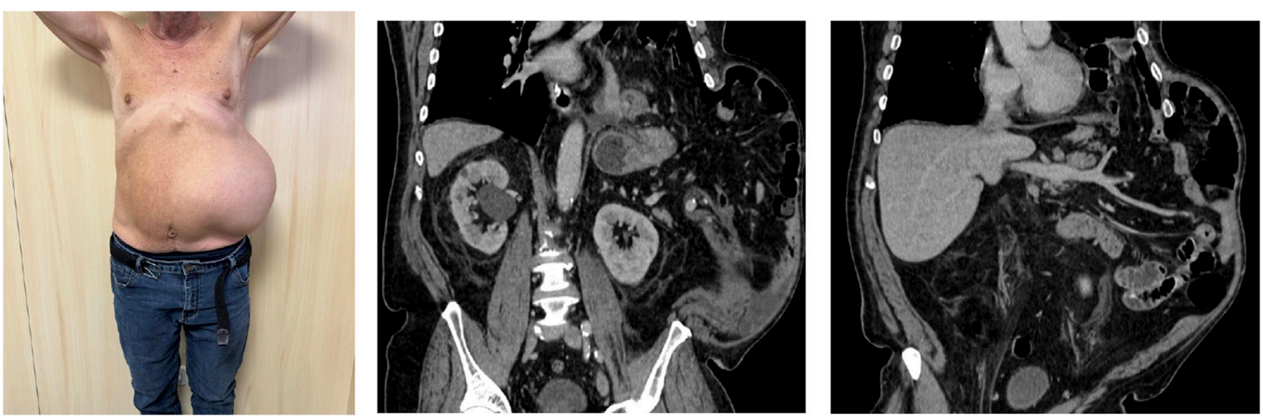

FIGURE 1 | Patient and preoperative CT scan.

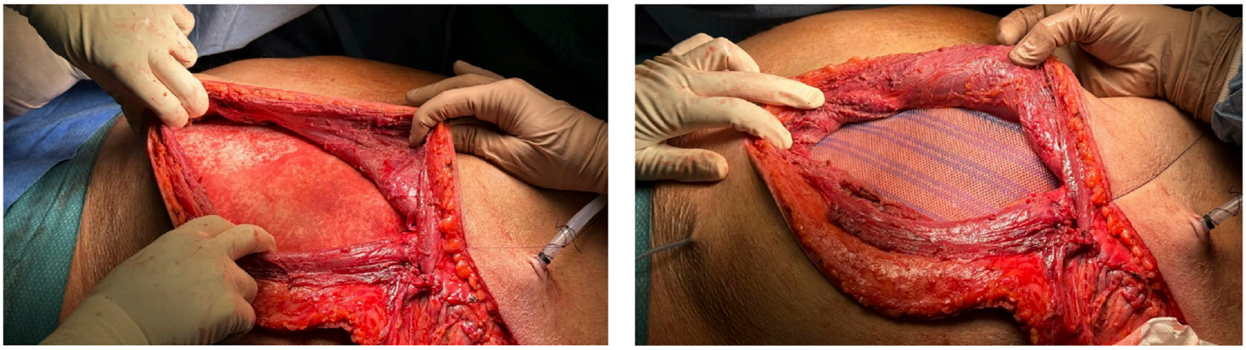

FIGURE 2 | Preperitoneal hernioplasty (Bio-A and polypropylene mesh).

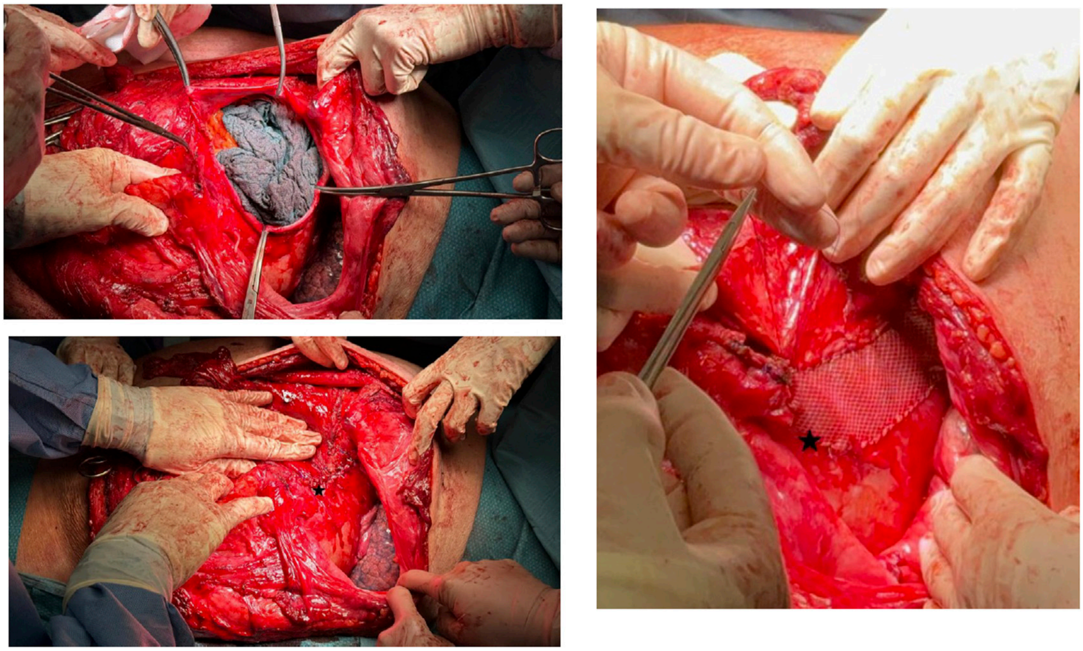

FIGURE 3 | Closure of the diaphragmatic defect with reinforcement mesh.

et al. described four cases of what they termed "abdominal intercostal hernia," defining it as the protrusion of abdominal viscera through an intercostal space following diaphragmatic herniation and intercostal muscle rupture [11]. Since then, this term has been used globally, often without specifying the anatomical areas involved. Gooseman et al. introduced the Sheffield classification, which considers the involvement of costal margin rupture, diaphragmatic rupture, and intercostal rupture [6]. More recently, Byers et al. analyzed management strategies based on this classification, distinguishing between conservative and surgical approaches [5]. Patients with isolated costal margin rupture often benefit from conservative management, with favorable outcomes, while diaphragmatic and/or intercostal ruptures typically require surgical repair [5]. We propose that the involvement of abdominal wall musculature should be integrated into the classification system, as this component is frequently overlooked but crucial in cases like the one presented. Proper management in such cases extends to abdominal wall repair.

A comprehensive, standardized classification system is critical to optimize the management of this pathology and achieve better clinical outcomes. Conventional CT and 3D imaging are generally employed to detect all anatomical defects [5]. While chest X-rays and ultrasound may also be used, they are less effective [13].

The surgical approach is not yet standardized, but it is essential to repair all components of the defect, including the diaphragm, intercostal muscles, abdominal wall, and costal margin, to minimize recurrence and postoperative pain. Open surgery via thoracic or thoracoabdominal incision remains the most common approach [5]. However, there are reports of successful laparoscopic repair, offering early mobilization and minimal postoperative discomfort, though with limited long-term follow-up [4, 14]. Early surgical intervention in scheduled cases can prevent complications such as incarceration, which significantly increases morbidity and mortality [10, 15, 16].

In conclusion, early surgical intervention is key to preventing complications. This case illustrates a rare and complex hernia that can develop in patients with severe COPD, especially after intense coughing. In this case, the severe post-pneumonia cough likely caused the rupture of the diaphragm and abdominal wall, leading to herniation. The strengths of this case include a successful multidisciplinary surgical approach and a favorable postoperative outcome. However, the patient's underlying pulmonary condition presents a risk of hernia recurrence. This case adds to the limited body of literature on such hernias, underscoring the importance of meticulous preoperative planning and postoperative management in similar cases.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because data about the patient is confidential. Requests to access the datasets should be directed to the local informatic health care system.

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Posterior Component Separation Technique—Original Transversus Abdominis Release (TAR) Technique

Jignesh A. Gandhi[1], Aarsh P. Gajjar[1], Pravin H. Shinde[1] and Sadashiv Chaudhari[2]*

[1]King Edward Memorial Hospital and Seth Gordhandas Sunderdas Medical College, Mumbai, India, [2]Jaslok Hospital, Mumbai, India

The history of ventral hernia repair techniques has seen substantial evolution, from primary suture repair to the introduction of mesh-based procedures, aiming to reduce recurrence rates. Notable advancements include the anterior and posterior component separation techniques. The Transversus Abdominis Release (TAR) technique, a refinement of the posterior approach, emerged to address challenges associated with complex ventral hernias. The TAR technique facilitates midline reconstruction, allowing large mesh placement while minimizing the need for subcutaneous dissection. Despite its benefits, TAR presents potential complications, emphasizing the necessity for meticulous preoperative assessment and training. The paper reviews the historical progression of hernia repairs, details the TAR technique, highlights indications, perioperative care strategies, surgical steps, postoperative management, technical challenges, and emphasizes the critical role of expertise in achieving successful outcomes in complex abdominal wall reconstruction.

Keywords: PCST, TAR, abdominal wall reconstruction, Yuri Novitsky, transversus abdominis release

INTRODUCTION

The history of ventral hernia repair techniques has evolved significantly over the years. Initially, primary suture repair was the mainstay of treatment, but this approach was associated with high recurrence rates due to the inherent tension in the repair.

The introduction of mesh-based repairs in the mid-20th century marked a significant advancement in hernia surgery. The use of synthetic mesh to reinforce the repair reduced tension on the suture line and significantly decreased recurrence rates. However, the placement of mesh in contaminated fields was associated with a high risk of infection [1].

Alfonso Roque Albanese pioneered incisions in the oblique muscles, resembling the Ramirez technique, now synonymous with anterior component separation for abdominal wall closure. He expanded his method to include incisions over the oblique minor and posterior rectus sheath, performing component separation hernia repairs in the 1960s to restore the midline without tension in large defects [2]. The Da Silva triple layer repair used the hernia sac to reinforce the rectus sheath, while the peritoneal flap hernia repair reinforced this repair by placing a prosthesis in the Rives-Stoppa plane as described by Andrew de Beaux, to reconstruct the midline without any additional components separation technique [3].

Concurrently, in 1965, French surgeons Dr. Jean Rives and Dr. Rene Stoppa initiated the posterior component separation technique (PCST). The Rives repair initially involved using sublay polyester mesh in the retro-rectus space for inguinal hernia repair. Dr. Stoppa extended this technique to

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***Correspondence**
Jignesh A. Gandhi,
jigneshkem@gmail.com

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ventral incisional hernias by dissecting the posterior lamina from the rectus muscles and placing polyester mesh in the preperitoneal or retro-rectus space [4]. These techniques gained popularity in the United States through the adaptation by Wantz for unilateral inguinal hernia repair [5]. However, traditional anterior component separation techniques were associated with potential wound complications and recurrence of hernias. This concept was further refined and officially termed "Component Separation" by Ramirez et al. in 1990 [6].

The development of anterior component separation (ACS) involved an incision in the external oblique aponeurosis and dissection between the external and internal oblique muscles. Despite providing greater medial advancement, ACS had higher rates of wound complications and hernia recurrence [7]. Challenges included skin necrosis, technical difficulties in certain patients, and notable wound complications like infection, hematoma, and seroma due to extensive dissection and vessel division [1].

Carbonell et al. [8] described a PCS technique involving lateral division of the Posterior Rectus Sheath (PRS), creating a plane between the Internal Oblique (IO) and Transversus Abdominis (TA) muscle. This technique allowed for myofascial advancement, enhancing midline fascial closure and providing greater space for mesh placement. While postoperative wound complications occurred in 15% of patients, only one patient experienced recurrence. A drawback of this technique was the division of neurovascular bundles, potentially leading to denervation of the RA muscle, which could result in various complications.

In response to these challenges, Yuri Novitsky and colleagues introduced the Transversus Abdominis Release (TAR) technique [9]. TAR is a surgical approach used for complex abdominal wall reconstruction, particularly in the context of large and complex ventral hernias [10, 11]. The development of the PCST, or TAR, was driven by the need for improved methods to manage complex abdominal wall hernias. Traditional ACS techniques had limitations, including the potential for wound complications and recurrence of hernias. The TAR technique was designed to overcome these challenges and improve patient outcomes.

The evolution of PCST from the Rives-Stoppa repair enables the advancement of the RA muscle, facilitating midline closure with the placement of a prosthetic material that extends beyond the retro-rectus space, eliminating the need for subcutaneous tissue dissection. Although not explicitly termed as PCST, the TAR technique reported by Novitsky et al. [9] allowed for bloodless dissection and provided sufficient space for mesh placement by entering the preperitoneal plane. However, this approach exhibited a 24% wound related complications and 4.7% hernia recurrence rate. TAR represents a further refinement of PCS, enabling closure of the PRS and anterior fascia along with the placement of a large mesh in the pre-transversalis pre-peritoneal plane (TAR plane) without disrupting the neurovascular bundles to the RA.

Further modifications of the TAR technique have been described to simplify the surgical procedure and offer additional advantages. For example, a bottom-up TAR technique has been proposed, which allows a simpler dissection beyond the retromuscular space to enable easy approach to perform TAR technique [12].

This emphasizes that the success of the TAR technique requires a thorough understanding of the abdominal wall anatomy, proper training, the adoption of a strict prehabilitation program, and large volumes of experience [10].

INDICATIONS

The TAR technique is primarily indicated for the repair of large and complex ventral hernias, including incisional hernias. Large hernias are defined as hernias with a fascial defect width greater than 10 cm or involving a significant portion of the abdominal wall, typically greater than 25% [13]. It is particularly useful when medial myofascial flap advancement is required [11]. TAR allows for the placement of a large prosthesis in the pre-transversalis pre-peritoneal plane, facilitating midline anatomical reconstruction. TAR is also effective for lateral hernias, particularly those involving the lumbar or flank regions, where traditional approaches may be insufficient for achieving durable repair [14]. It has been shown to be effective in patients with significant comorbidities, such as diabetes and chronic obstructive pulmonary disease [15].

PERIOPERATIVE CARE AND OPTIMIZATION

Prior to complex abdominal wall reconstruction, a thorough preoperative assessment is recommended. This approach is part of a comprehensive preoperative care strategy that adopts a multidisciplinary team (MDT) approach. This collaborative effort involves specialists from diverse fields, including surgeons, radiologists, anaesthesiologists, nutritionists, and psychologists. Together, they focus on assessing pivotal factors such as abdominal wall musculature, hernia defect dimensions, hernia contents, and loss of domain. The MDT engages in a structured learning process to educate all members with specific learning points pertinent to the procedure. Meticulous preoperative habilitation and comprehensive knowledge about the procedure enhance a smooth post-operative recovery with best surgical outcomes.

Preoperative CT imaging of the abdomen is of great significance, as it offers comprehensive insights into the abdominal wall's structure, hernia defect dimensions, contents, loss of domain, muscle thickness, retroperitoneal abnormalities, and the previously placed mesh plane. Loss of domain is defined as the ratio of hernia sac volume to the abdominal cavity volume exceeding 20%, indicating that a significant portion of the viscera is contained within the hernia sac. On preoperative CT, surgeons should measure the width and length of the fascial defect and the hernia sac to plan for adequate mesh overlap and ensure complete coverage. Additionally, evaluate muscle thickness, retroperitoneal abnormalities, and previous mesh placement.

Preoperative pulmonary function tests (PFTs) are conducted for all patients. PFTs are recommended for patients with a history of pulmonary disease or significant smoking history to assess baseline lung function and optimize perioperative care [15]. Patient optimization before surgery is crucial for favourable surgical outcomes. Patients with colon as hernia content should receive bowel preparation with polyethylene glycol (PEG) before surgery. Studies suggest that bowel preparation with polyethylene glycol (PEG) can reduce postoperative complications in patients with colon as hernia content, although this is not universally required [16]. There are increased complications in active smokers, poorly controlled diabetic patients, and those who are obese or malnourished [16, 17]. Hence, efforts are made to ensure smoking cessation for at least 4 weeks, strict glycemic control (HbA1c levels < 7 gm %), and weight reduction aiming for a BMI of <30 kg/m^2 before elective repair. While aiming for a BMI of <30 kg/m^2 is ideal, a more practical approach is to encourage weight reduction and improve nutritional status as much as possible preoperatively [18]. The team addresses patient-specific considerations like smoking cessation, glycemic control, and weight reduction. These factors play a crucial role in optimizing surgical outcomes and mitigating potential complications linked to smoking, poorly controlled diabetes, obesity, or malnutrition [19]. Progressive corset tightening is supported by anecdotal evidence and expert opinion, but more research is needed to establish its benefits definitively.

The procedure should be carried out under general anaesthesia, with epidural catheter for postoperative regional patient-controlled analgesia (PCA) and prophylactic antibiotics should be given 1 h before incision as per standard institutional protocols. In addition to epidural anesthesia, quadratus lumborum (QL) blocks have shown efficacy in providing postoperative pain relief [20].

Malnutrition is defined by criteria such as unintentional weight loss >10% in the past 6 months, low serum albumin (<3.5 g/dL), and poor dietary intake. Patients should be assessed using tools like the Subjective Global Assessment (SGA) and referred to a nutritionist if identified at risk. A high-protein diet is defined as 1.2–1.5 g/kg body weight/day, and patients should be referred to a nutritionist if their dietary intake is inadequate.

A holistic approach should be adopted for all patients, incorporating anatomical optimization via an abdominal corset designed 2 weeks pre-surgery, physiological optimization using incentive spirometry and progressively tightening the corset to simulate postoperative abdominal pressure increase, nutritional optimization with a high-protein diet, and psychological optimization through preoperative counselling.

SURGICAL TECHNIQUE

The TAR technique has represented a significant milestone in the field of complex abdominal wall reconstruction. This innovative approach involves the development of the retromuscular space, further dividing the posterior lamella of IO muscle to enable division of TA muscle, and getting access into the TAR plane. Gandhi et al. [21] proposed a comprehensive set of procedural principles and guidelines, commonly referred to as the "decalogue," within the TAR surgical technique. This decalogue encapsulates a refined series of steps and considerations, offering a structured and standardized approach to TAR, thereby enhancing its reproducibility and potentially optimizing patient outcomes.

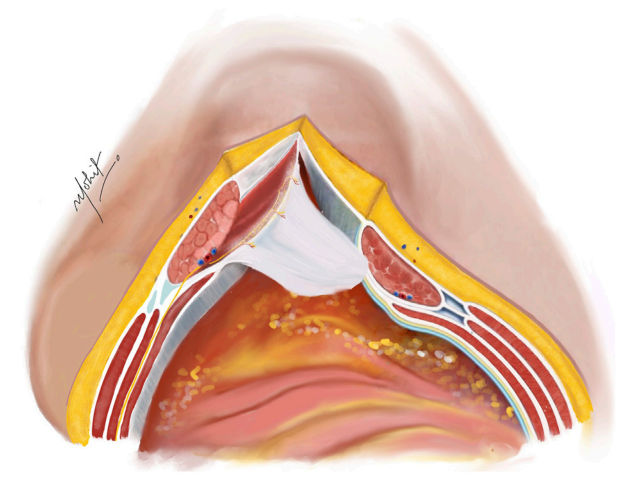

FIGURE 1 | Incision taken on the PRS 5 mm from the medial edge of the rectus abdominis muscle. The hernial sac is kept continuous with the PRS. Illustration by: Dr. Mohit Badgurjar.

Adhesiolysis

A midline laparotomy procedure includes scar excision and entry into the abdomen, guided either by physical examination, selecting an untouched abdominal area, or by reviewing CT scans that display clear pre-peritoneal fat separating the abdominal wall and viscera. Particular attention is paid to avoid visceral injury when the hernial sac is close to the skin. The hernia sac is typically opened in the midline and, as per the case requirements, is often conserved and maintained in continuity with the PRS. Delicate dissection is done with use of cold scissors and appropriate monopolar and bipolar energy devices to perform adhesiolysis from the undersurface of the anterior abdominal wall and the abdominal scar. Inter-bowel adhesiolysis is not mandatory unless patient has presented with episodes of bowel obstructions in the past.

Placement of the TAR towel

Following this step, a sizable sterile moistened towel is introduced intraperitoneally and carefully positioned, being tucked into the paracolic gutters on the sides, extending inferiorly into the pelvis, and superiorly positioned beneath both domes of the diaphragm. This measure serves the purpose of shielding and safeguarding the viscera throughout the ensuing dissection process.

Creation of the Rives-Stoppa Plane

An incision is made on the PRS, positioned 5 mm from the midline to enter the Rives-Stoppa plane (**Figure 1**). This incision is then extended along the entire length in both cranial and caudal directions, revealing the Rives-Stoppa plane. Blunt dissection is

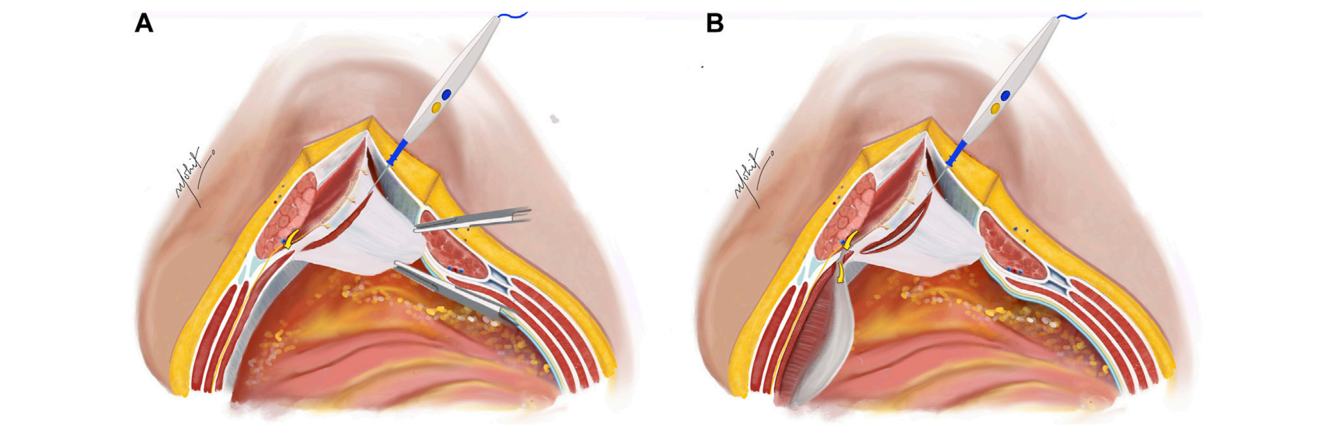

FIGURE 2 | (A) The Rives-Stoppa plane is developed. Neurovascular bundles are identified and an incision is taken on the posterior lamella of IO 5 mm medial to the neurovascular bundles to expose the TA muscle. **(B)** Incision taken on the TA muscle to enter the TAR plane. Illustration by: Dr. Mohit Badgurjar.

employed to carefully develop the plane towards the linea semilunaris, while an assistant retracts the RA muscle superiorly and away from the PRS. In special situations with large sac or wide neck hernias, the medial edge of the RA muscle is identified by palpation or by twitching of its fibres to electrical stimuli. This ensures correct access to the Rives-Stoppa plane. Further, the small perforators from the RA to the PRS are divided with the help of bipolar energy until the lateral most edge of the dissection is reached. Here, the paired neurovascular bundles, representing the linea semilunaris mark the lateral extent of dissection. This can be identified as the "lamppost sign" [22]. Continuing below the arcuate line, dissection progresses to unveil the pre-peritoneal plane, where identification and preservation of the deep inferior epigastric vessels, situated in the pre-transversalis plane along the posterolateral surface of the RA muscle, are crucial. Further inferiorly, dissection extends to reveal the space of Retzius, exposing the pubic symphysis and the Cooper's ligaments.

In female patients, division of the round ligament can be performed to facilitate good mesh overlap. The division should be done close to the peritoneum to prevent neuropraxia associated with damaging the genital branch of genitofemoral nerve, with the help of energy device or clips.

Release of TA Muscle

The subsequent step involves a 5 mm incision on the posterior lamella of the IO aponeurosis, positioned medially to the neurovascular bundles to expose the underlying TA muscle (**Figure 2**). This incision is typically performed in the middle third of the plane where the TA fibres are muscular, compared to the lower third where the muscle is more aponeurotic. Utilizing the "bottom-up" approach in select cases becomes feasible due to this fat presence, facilitating the establishment of TAR plane. The TA muscle is raised using Lahey's forceps, and small bites of short bursts of monopolar and/or bipolar energy is used to divide the muscle fibres. This approach continues in the cranial as well as caudal aspects of the plane.

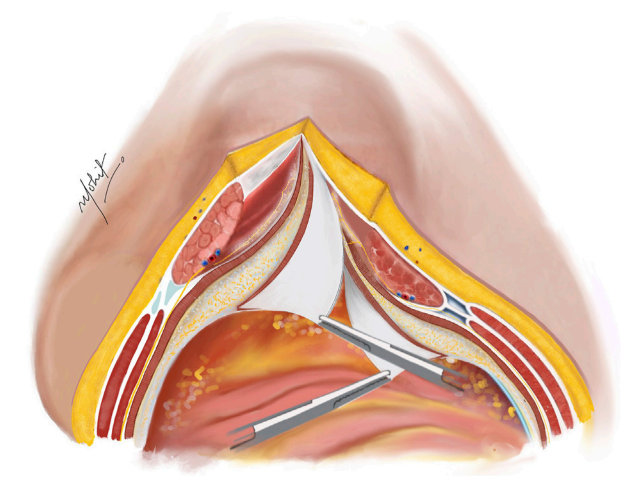

FIGURE 3 | The TA muscle lifted up and away from the fascia transversalis. The TAR plane is developed laterally until the psoas muscle. Illustration by: Dr. Mohit Badgurjar.

Creation of the TAR Plane

Using novel right-angled retractor, the assistant elevates the abdominal wall upward, while the surgeon's left hand applies a counter pressure over the TAR plane pushing the TA muscles upwards approaching the lateral extraperitoneal space (**Figure 3**). An additional mop is positioned to provide added safeguarding over the fascia transversalis/peritoneum. Employing a peanut dissector, the TA muscle is lifted superiorly and separated from the transversalis fascia/peritoneum. Lateral dissection is extended toward the psoas muscle, avoiding exposure of ureters. The dissection extends caudally up to the space of Retzius in the midline, and laterally the space of Bogros. In select cases of M1 and M2 hernias, the dissection extends cranially in the pre-diaphragmatic space up to the central tendon of diaphragm. Any peritoneal button holes are sutured using

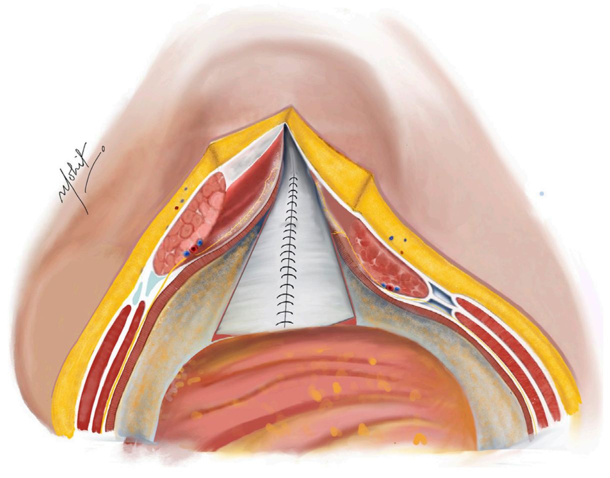

FIGURE 4 | Complete closure of the PRS done with absorbable sutures after completion of bilateral TAR; in cases of incomplete approximation of the posterior rectus sheath (PRS), hernial sac kept continuous with the PRS is used to achieve closure. Illustration by: Dr. Mohit Badgurjar.

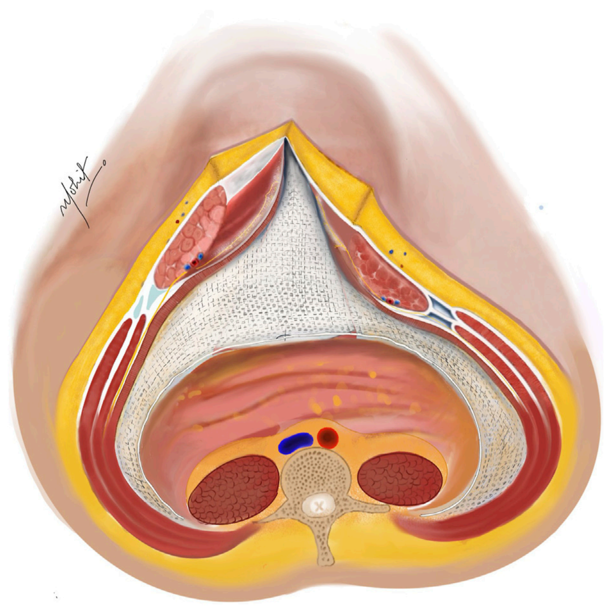

FIGURE 5 | A medium weight polypropylene mesh placed in the TAR plane and fixed laterally under physiological tension. Linea alba reconstructed ventrally to the mesh using non-absorbable sutures. Illustration by: Dr. Mohit Badgurjar.

absorbable material. For larger defects, omentum is used for reinforcement.

TAR on the Other Side

A similar process is carried out on the opposite side by dividing the posterior lamella of IO, further dividing the TA muscle and creating a TAR plane. This enables substantial medialisation of the RA muscles (8–12 cm on each side) [23].

Closure of the PRS

The PRS is approximated in the midline after removal of the TAR towel with closely spaced 5–8 mm suture bites using 1-0 absorbable polyglactin suture with a cranial and a caudal approach completing it in the middle (**Figure 4**). In difficult cases of PRS approximation, the use of polyglactin mesh, biosynthetic mesh and omentum as a patch is recommended. It is important to monitor the peak/plateau pressure during and at the end of PRS closure. Following this, a transversus abdominis plane (TAP) block is administered by injecting liposomal bupivacaine into the intramuscular plane between the IO and TA muscles using an 18-gauge needle under direct visualization [20].

Placement of the Mesh

Two 30 cm × 30 cm medium weight polypropylene meshes (MWPP) arranged in a home plate configuration are placed in the TAR plane. Using two meshes in a home plate configuration provides better coverage and ensures overlap, especially in very large defects. However, a single large mesh may suffice for smaller defects. Optional fixation of the mesh can be done with transfascial fixation under physiological tension to prevent folding of the mesh laterally (**Figures 5**, **6**). Two closed suction drains are placed in the TAR plane to mitigate seroma formation.

Closure of the Anterior Rectus Sheath (ARS)

The ARS is then approximated with 1-0 interrupted nylon sutures with a cranial and a caudal approach to reconstruct the midline in front of the mesh (**Figure 5**). Interrupted nylon sutures provide greater tensile strength and allow for adjustments in tension during closure. However, running slowly absorbable sutures are also effective and commonly used. Monitoring of the peak/plateau pressure is pertinent during this step to prevent future compartment syndrome [24]. Surgeons and anaesthesiologists should monitor for signs of abdominal compartment syndrome, such as elevated peak inspiratory pressures (>20 cm H_2O) and decreased urine output. As a mitigation strategy for the difficult closure of ARS, a heavy weight polypropylene (HWPP) mesh can be used to bridge the midline. When using heavyweight polypropylene mesh to bridge the midline, it should be secured with non-absorbable sutures to the fascia on either side, ensuring no tension on the mesh [11].

Subcutaneous Tissue and Skin Closure

A flat drain is inserted into the subcutaneous plane to avoid seroma. The subcutaneous tissue is stitched using a 2-0 polyglactin absorbable material, and the skin is closed with staples or interrupted sutures. An accurately fitted abdominal corset is applied immediately.

DISCUSSION

Pros and Cons of TAR Technique

The Transversus Abdominis Release (TAR) technique facilitates substantial medial advancement of the rectus abdominis muscles,

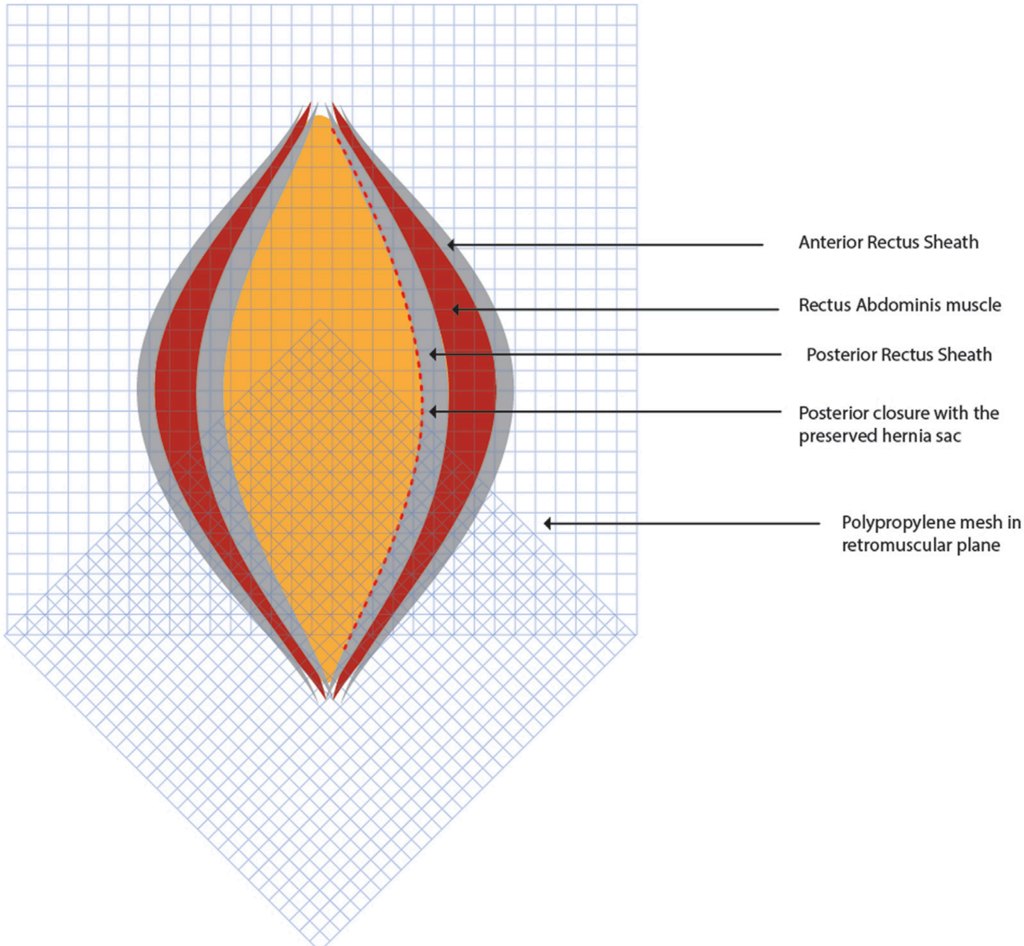

FIGURE 6 | Two 30 cm × 30 cm medium weight polypropylene meshes are placed in the TAR plane in home plate configuration. Figure inspired from Gandhi et al [21].

typically achieving 8–12 cm on each side, in contrast to the 5–7 cm achieved with anterior component separation [7, 23]. This method is associated with reduced wound complications due to the minimized need for subcutaneous dissection [15]. Additionally, TAR enhances mesh integration and decreases infection risk owing to the better vascularization of the placement site [10]. The technique is particularly effective for patients with significant comorbidities such as obesity and diabetes [15].

However, the TAR technique demands a high level of expertise and an in-depth understanding of abdominal wall anatomy, limiting its practice to highly skilled surgeons [16]. The steep learning curve associated with TAR necessitates extensive training and practice, which can impede its widespread adoption [25]. Despite its advantages, TAR can result in complications such as seroma formation, wound infection, and recurrence, although these rates are generally lower compared to other techniques [11]. Furthermore, the procedure often requires longer operative times and specialized equipment, making it resource-intensive [10].

It is crucial for TAR to be performed by surgeons with specialized training and extensive experience in hernia repair to ensure optimal outcomes and minimize potential complications [16].

Technical Challenges and Mitigation Strategies

The original TAR technique, as described by Yuri Novitsky, has been associated with several potential complications and limitations. Surgical site events, including infections, have been reported in up to 18.7% of cases, with surgical site infections specifically occurring in 9.1% of cases. In some instances, these complications have necessitated mesh debridement, although complete mesh explantation has been reported as rare. Despite the technique's overall effectiveness, recurrences have been reported in up to 3.7% of patients with at least 1-year follow-up [11].

Furthermore, the TAR technique requires a thorough understanding of the abdominal wall anatomy and proper training, which may limit its widespread adoption [10]. One significant concern lies in the delicate dissection required to access the TAR plane, avoiding neurovascular bundles, and adapting to anatomical landmarks. Potential complications include “mickey mouse” hernia due to injury to the semilunar line, intraparietal hernias from improper closure of the posterior rectus sheath, and consequences of holes in the posterior layer. Meticulous attention to surgical technique can mitigate these risks.

Surgeons embarking on the implementation of the PCSTAR techniques should undergo specialized training in designated centres of excellence. This training encompasses immersive experiences in cadaver workshops, providing hands-on practice and refinement of the intricate dissection techniques required for accessing the TAR plane [25]. Additionally, surgeons have access to a wealth of educational resources, including peer-reviewed videos and articles, which offer valuable insights and best practices for executing PCSTAR with precision and proficiency. This comprehensive training regimen equips surgeons with the necessary skills and knowledge to navigate the technical challenges associated with PCSTAR, emphasizing the critical role of expertise and meticulous surgical technique in achieving successful outcomes in complex abdominal wall reconstruction.

Postoperative Care and Outcomes

Postoperative care prioritizes minimizing the use of narcotics while focusing on measures like adequate regional PCA, prophylaxis against deep vein thrombosis, utilization of abdominal corsets, prescribed bed rest, chest physiotherapy and adherence to the Enhanced Recovery After Surgery (ERAS) protocol. Drain removal is contingent on output, and examining the midline wound is delayed as a standard procedure. Long-term outcomes are evaluated through regular follow-up appointments and CT scans.

To reduce reliance on narcotics, the TAP block is utilized for effective pain relief in most patients. Additionally, acetaminophen is administered to provide supplementary pain relief. Initiation of deep vein thrombosis prophylaxis aligns with current recommendations [26]. Patients are advised to continue wearing the abdominal corset, start early mobilization to reduce the risk of thromboembolism and improve recovery, bed rest should be minimized, and follow an ERAS protocol with a shift to clear liquids on the first day after surgery [27, 28]. Transition to a soft diet occurs after the complete resolution of postoperative ileus. Drains are removed when daily output falls below 20 mL. Inspection of the midline wound is deliberately postponed, unless dressing soakage necessitates earlier attention. Incisional wound vacs can be beneficial in reducing infection rates and improving healing. Dressings should be changed based on clinical assessment.

Post discharge, follow-up should be scheduled at 2 weeks, 1 month, 3 months, 6 months, and annually thereafter, with additional visits as needed based on clinical findings. Routine CT scans are recommended at 6 months and 1 year postoperatively to monitor for hernia recurrence and other complications.

CONCLUSION

In conclusion, the evolution of ventral hernia repair techniques has progressed significantly over time, transitioning from primary anatomical repair to components separation technique and subsequently introducing complex surgical approaches such as the TAR technique. TAR, as a refined component of the posterior component separation technique, has demonstrated its efficacy in managing large and complex ventral hernias, achieving substantial medialization of rectus abdominis muscles and facilitating midline closure while providing a space for large mesh placement. However, the successful application of TAR demands a thorough understanding of abdominal wall anatomy, specialized training, and adherence to strict prehabilitation protocols.

AUTHOR CONTRIBUTIONS

JG was overall incharge from preparation to documentation. AG helped writing the manuscript, PS and SC contributed to references. All authors contributed to the article and approved the submitted version.

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CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

PUBLISHER’S NOTE

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Limitations of Transversus Abdominis Release (TAR)—Additional Bridging of the Posterior Layer And/Or Anterior Fascia Is the Preferred Solution in Our Clinical Routine If Primary Closure is Not Possible

Hartwig Riediger and Ferdinand Köckerling*

Vivantes Humboldt-Klinikum, Berlin, Germany

Background: By separating the abdominal wall, transversus abdominis release (TAR) permits reconstruction of the abdominal wall and the placement of large mesh for many types of hernias. However, in borderline cases, the mobility of the layers is inadequate, and additional bridging techniques may be required for tension-free closure. We now present our own data in this regard.

Patients and Methods: In 2023, we performed transversus abdominis release on 50 patients as part of hernia repair. The procedures were carried out using open (n = 25), robotic (n = 24), and laparoscopic (n = 1) techniques. The hernia sac was always integrated into the anterior suture and, in the case of medial hernias, was used for linea alba reconstruction.

Results: For medial hernias, open TAR was performed in 22 cases. Additional posterior bridging was performed in 7 of these cases. The ratio of mesh size in the TAR plane to the defect area (median in cm) was 1200cm^2/177 cm^2 = 6.8 in patients without bridging, and 1750cm^2/452 cm^2 = 3.8 in those with bridging. The duration of surgery (median in min) was 139 and 222 min and the hospital stay was 6 and 10 days, respectively. Robotic TAR was performed predominantly for lateral and parastomal hernias. These procedures took a median of 143 and 242 min, and the hospital stay was 2 and 3 days, respectively. For robotic repair, posterior bridging was performed in 3 cases.

Discussion: Using the TAR technique, even complex hernias can be safely repaired. Additional posterior bridging provides a reliable separation of the posterior plane from the intestines. Therefore, the hernia sac is always available for anterior reconstruction of the linea alba. The technique can be implemented as an open or minimally invasive procedure.

Keywords: incisional hernia, transversus abdominis release, robotic abdominal wall surgery, open surgery, bridging

Correspondence
Hartwig Riediger,
hartwig.riediger@vivantes.de

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BACKGROUND

The transversus abdominis release (TAR) technique first described in 2012 by Novitsky et al. is used predominantly to repair wide medial hernias (EHS W3, >10 cm) [1]. In 2016, a modified version of the technique was described by Pauli et al. to treat parastomal hernias [2]. The separation of the boundaries of the abdominal components permits the placement of meshes with a large overlap (TAR mesh) in the newly created extraperitoneal space. Furthermore, the separation of the abdominal wall into an anterior muscular plane and a posterior fascial plane increases the mobility of both layers. When properly performed, the technique ensures impressively good perioperative outcomes and rapid patient recovery [3, 4]. The recurrence rate is low, even in the long term [5, 6].

TAR can be performed using either open or minimally invasive surgery (MIS). For the latter, robotic surgery has become increasingly established. While the investment in equipment and instrumentation is considerable, the number of procedures carried out continues to grow. Based on our experience, one of the particular benefits of robotics is that lateral and parastomal hernias can also be repaired. If a mesh is to be placed in the extraperitoneal space, the anatomy of the abdominal wall in this location requires TAR regardless of the size of the hernia.

One of the difficulties that can be encountered when repairing complex abdominal hernias is the generation of excessive tension in the reconstruction phase. In the most unfavourable cases, this can even lead to life-threatening abdominal compartment syndrome. The TAR technique can recreate the physiologic abdominal volumes [7, 8]. However, if a plane cannot be closed, mesh-based anterior [8, 9], and much more commonly posterior [5, 10–18], bridging concepts have already been described for TAR. They are also firmly established in our clinical routine. Based on our own data from 2023, we can therefore present details of the surgical indications and the clinical treatment results of open and robotic repair with and without bridging.

We have been gaining practical experience with TAR for approximately 5 years now. Since the start of 2023 we have also had the privilege of using a DaVinci (Intuitive Surgical, Sunnyvale, CA, United States) system for hernia surgery. We have routine access to this 1 day a week. While the choice of procedure (open vs. robotic) is influenced by the different experience horizons, trends towards typical indications and concepts are emerging.

PATIENTS AND METHODS

In the period from January 01, 2023 to December 31, 2023, 88 medial and 15 lateral incisional hernias and 9 parastomal hernias were operated on in our hospital. Of these 112 patients, only those, (n = 50); (medial: n = 27, lateral: n = 14, parastomal: n = 9) who underwent open or minimally invasive transversus abdominis release with mesh placement were analysed in this study (**Table 1**). All patients were seen preoperatively by a qualified (FEBS AWS) surgeon and surgical repair by robotic or open technique was indicated. Due to the recent introduction of robotic hernia surgery last year, larger hernias were predominantly operated on using the open technique. Apart from our concept of TAR and optional bridging, no other hernia-specific reconstruction techniques were used. This was a retrospective study of prospectively collected data.

TABLE 1 | Secondary hernias (n = 50) repaired in TAR technique in the period January 01, 2023 to December 31, 2023.

	Medial (n = 27)	Lateral (n = 14)	Parastomal (n = 9)
Open (n = 25)	22	1	2
Robotic (n = 24)	4	13	7
Laparoscopic (n = 1)	1	0	0

A particular focus of the study was the perioperative data of two TAR patient groups: the treatment outcomes of the clinically relevant group of patients with medial ventral hernia and open TAR repair were compared with respect to bridging (yes/no). The second analysis was for patients who underwent robotic repair of a medial, lateral or parastomal hernia. The open and robotic TAR surgical techniques have already been described in detail. We will therefore limit ourselves here to describing the technical aspects related to bridging. The surgical procedure was selected after individual assessment.

According to our clinical experience and a recent theoretical work-up in our group, patients with a defect width of 17 cm or more on the preoperative CT scan have a high probability of needing additional bridging [19]. We also expect posterior bridging in lateral defects of smaller dimensions when unilateral TAR is indicated to create a large extraperitoneal space for adequate mesh overlap (**Figure 4**).

Steps in Open TAR Repair With Additional Bridging

The first step is to gain direct access to the abdominal cavity without developing the hernia sac from the subcutaneous layer. This means that the hernia sac will be available later for reconstruction of the linea alba. TAR is known to cause only limited medialisation in the anterior plane [20]. Deliberately leaving the hernia sac in place meant that we also had to rethink our views on the open concepts used up until now.

Next, adhesions are taken down from the anterior abdominal wall in all four quadrants. Interenteric adhesiolysis is only performed in patients with a history of impaired passage. The next step is to enter the retrorectus space.

It may be difficult to open the retrorectus space because the muscles are not only displaced laterally but are also compressed and narrowed. On CT, roll-shaped thickening of the rectus muscles is typically seen. After opening the medial edge, the posterior layer can be grasped with clamps and exposed. The TAR itself is then performed in a top-down or bottom-up technique parallel to the linea semilunaris with strict preservation of the neurovascular bundles that enter the retrorectus space 1–2 cm medial to the lateral margin. The extensions of the transversus

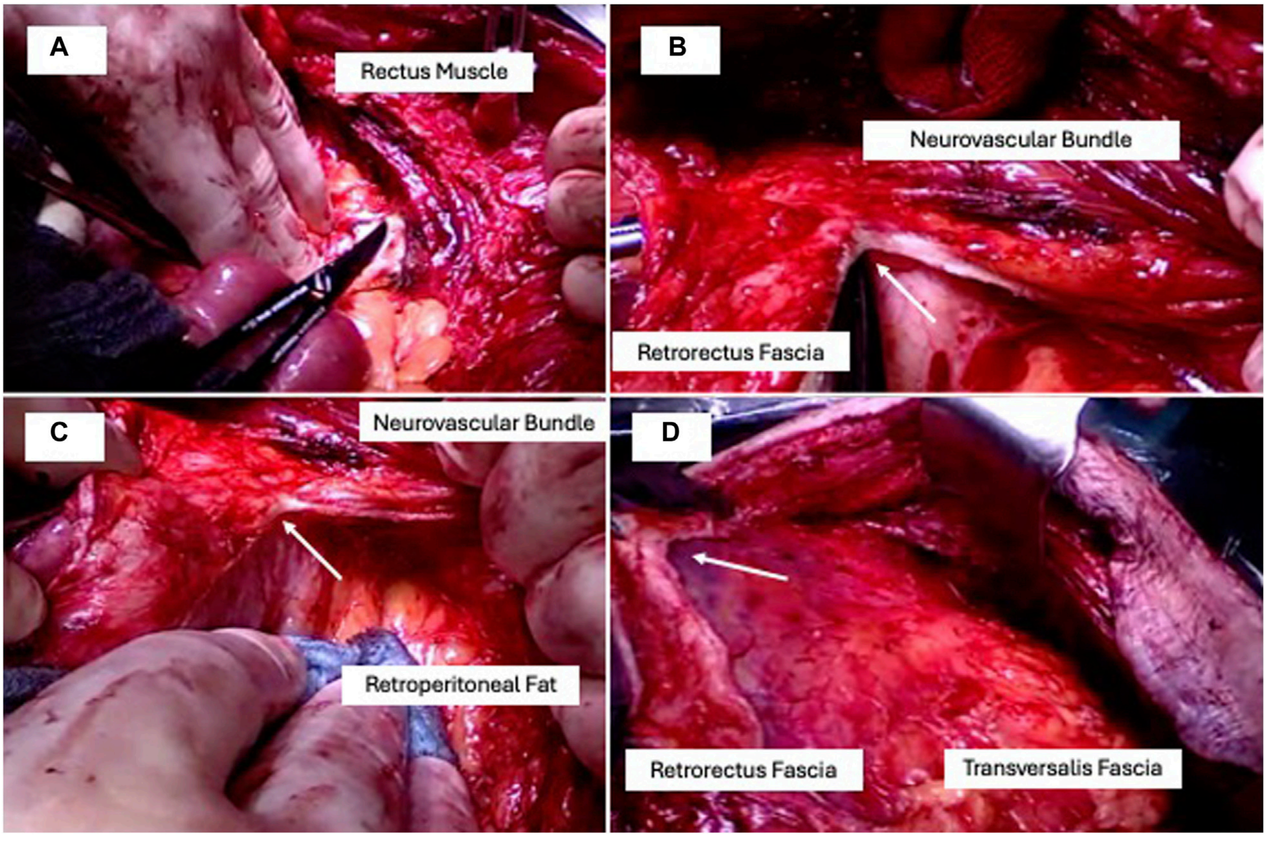

FIGURE 1 | TAR in four steps: **(A)** retrorectus access, **(B)** retrorectus fascia dissection (arrow) medial to the neurovascular bundles in a bottom-up direction starting at the linea arcuata, **(C)** complete lateral mobilisation to the retroperitoneal fat, **(D)** complete cranial dissection ending dorsal to the processus xiphoideus parallel to the linea semilunaris.

abdominis (TA) reach cranially as far as the retrosternal fat tissue and merge with the diaphragm muscles. By detaching the muscles along the linea semilunaris, a common mesh plane is created from lateral to cranial and similarly in the lower abdomen, now extending from the retroxiphoid to the retro-symphyseal space.

At the end of this release phase an anterior muscular plane and a posterior fascial plane will have been created (**Figure 1**). The posterior plane is a freely mobile structure. The anterior plane merges with the hernia sac, which remains intact, and the laparotomy incision site. Maximum mobilisation of the transversalis fascia (posterior plane) is routinely achieved in all cases upon reaching the retroperitoneal fat tissue (**Figure 1D**).

Posterior bridging is now indicated if it is not possible to close the posterior plane without tension. Posterior bridging is not an alternative to complete TAR mobilisation but our routinely performed technique in non-closable layers. Our preference here is to use a long-term absorbable mesh with an enteric adhesion barrier in an inlay technique. For this purpose, a long-term absorbable mesh made of poly-4-hydroxybutyrate with Sepra coating (Phasix ST, BD Bard, Karlsruhe, Germany) has proven its effectiveness in practice (**Figure 2**).

After closing the peritoneal space, the TAR mesh is placed. This should extend on both sides lateral to the retroperitoneal space and provide retroxiphoid and retro-symphyseal overlap. As standard practice, we use a Parietene macroporous mesh (Medtronic, Meerbusch, Germany) which is placed without further fixation. It may be necessary to suture together several meshes to ensure the overlapping of large defects or to fit the meshes at the edges. The TAR mesh must fully cover the newly created extraperitoneal space. Wound drains are placed on the TAR mesh and, if necessary, also at another location.

Direct closure is performed in the anterior plane with reconstruction of the linea alba. If this cannot be done while maintaining adequate strength, a non-absorbable or long-term absorbable mesh is used for prosthetic replacement of the linea alba and is sutured to the anterior fascial edge in a tension-free inlay technique. The skin is closed with skin clips, which are left in place for at least 3 weeks. An abdominal belt is applied under anesthesia. As soon as there is only a little wound drainage or the drains have been removed, we aim to discharge patients.

Steps in Robotic TAR Repair With Additional Bridging

Patient positioning is done in physiological hyperextension. The arms are adducted and placed beside the torso. For unilateral TAR, it is helpful to position the patient close to the opposite edge of the table so that the arm can also be positioned dorsally to the

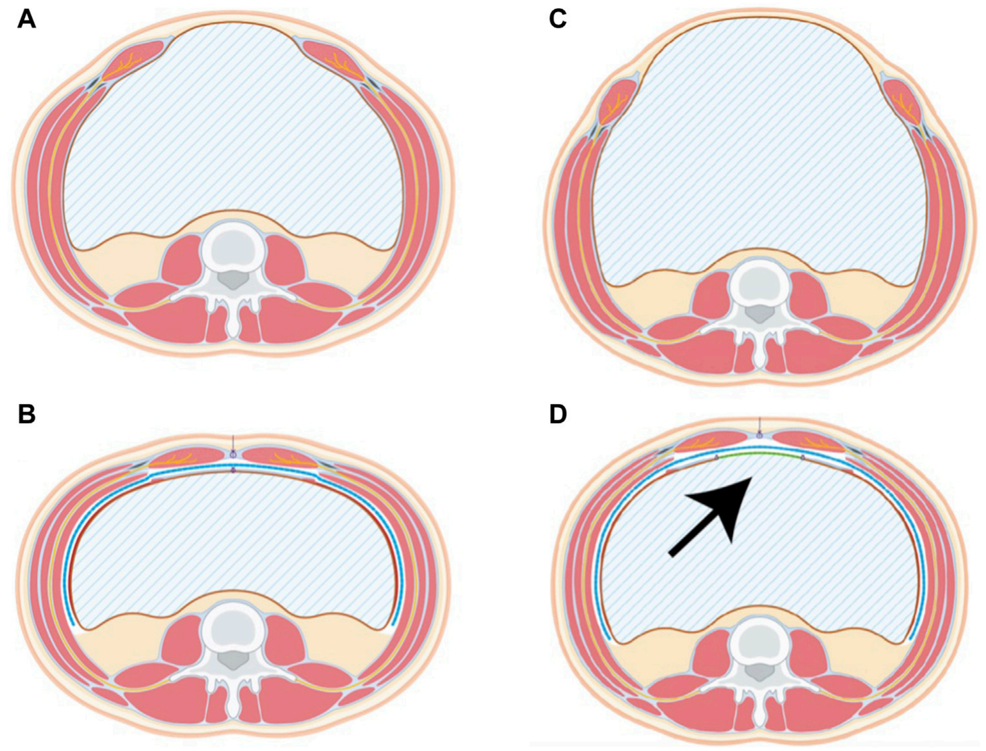

FIGURE 2 | Pre- and Postoperative scheme of the TAR procedure without bridging **(A,B)** and with bridging **(C,D)**. The TAR Mesh (blue line) covers the extraperitoneal space completely while the posterior bridging mesh (arrow, green line) delimits the abdominal cavity. Remnants of the sac are used for linea alba reconstruction in both cases.

body axis. This increases the mobility of the robotic arms and, in particular, facilitates ipsilateral entry into the abdominal wall. We usually place a 12 mm assist in the left or right ipsilateral upper abdomen using the open technique. The robotic trocars are then inserted along the anterior axillary line. After ventral adhesiolysis, an incision is made in the abdominal wall along the midline and this is followed by TAR preparation.

As in open surgery, we consistently divide the hernia sac from the posterior plane. It has been revealed that the hernia sac tissue cannot be developed in continuity anyway in incisional hernias and is then better integrated as a seam bearing into the anterior suture. Primary suture closure of the posterior plane inevitably results in plication of the posterior plane and thus a loss of surface area, which in small defects can be easily compensated for by the generously mobilised posterior plane. However, for large defects it is advisable to perform posterior bridging. Using this concept, the size of the extraperitoneal space is preserved and a non-absorbable TAR mesh with adequate overlap can be placed. This approach can also be applied to repair parastomal hernias. On the one hand, posterior bridging can be avoided by a more extensive or even bilateral open TAR. On the other hand, more patients may benefit from shorter operative times with minimally invasive TAR when posterior bridging is applied. After the placement of the TAR mesh, the extraperitoneal space is closed with sutures.

Postoperative Course

Following open or robotic repair, patients are extubated and routinely monitored in the recovery room. Transfer to the intensive care unit is not routinely required. The goal is to mobilise patients from postoperative day 1 and initiate food intake. All patients receive antithrombotic medication according to the guideline recommendations.

Perioperative Data

The procedures were performed as open and minimally invasive (conventional laparoscopic and robotic) operations. Robotic repair was carried out with a daVinci X system (Intuitive Surgical, Sunnyvale, CA, United States).

Preoperative sectional imaging was performed on all patients. Diagnostic CT imaging without contrast media is sufficient. The hernia area was calculated as an ellipse using the measured length and width (hernia area = length/2*width/2*π). The EHS classification was used to categorise hernias.

We use the term "TAR mesh" to denote a non-absorbable mesh that is placed with a wide overlap in the newly created extraperitoneal space. The area of the mesh used was calculated as a rectangle (mesh area = length*width) and the results were summed in the case of multiple meshes.

Postoperative Complications Were Graded According to the Dindo-Clavien Classification System.

Patient and procedure data were prospectively documented in the Herniamed Registry and retrospectively analysed. All patients gave informed consent for the documentation of their data in Herniamed. Statistical analysis of the 22 patients in **Table 1** was performed with IBM SPSS (Version 25) using Fisher's exact test (proportion of W3 hernias and morbidity) and non-parametric Mann Whitney U tests (age, BMI, defect width, defect length, defect size, TAR mesh size, duration of surgery, hospital stay in days).

RESULTS

In the 12-month period from January 01, 2023 to December 31, 2023, transversus abdominis release was performed on 50 patients as part of hernia repair. The hernias repaired were 41 ventral incisional hernias (medial: n = 27, lateral: n = 14) and 9 parastomal hernias. The median age of the patients was 64 years (24–85). The median BMI was 29 kg/m2 (21–48). Relative to the total group, morbidity was (CD1-5) 28% (n = 14). Minor complications (CD1+2) occurred in 18% (n = 9) of cases. However, surgical revision was needed in three cases (6%, CD 3b). Mortality (CD5) was 2% (n = 1) due to one patient dying of fulminant pulmonary embolism during mobilisation on postoperative day 1 following a robotic Pauli procedure.

TAR was carried out in 25 cases in open technique and in 25 cases in minimally invasive technique (robotic: n = 24, laparoscopic: n = 1). In the open surgery group, 22/25 of the hernias had a medial location. By contrast, only 5/25 of the minimally invasively repaired hernias had a medial location. The majority of the robotically repaired hernias were lateral or parastomal hernias (**Table 1**).

In the clinically relevant group of patients with medial hernia (n = 22) who underwent an open TAR procedure, 91% (20/22) had a W3 hernia. The median defect area in the entire group was 289 cm^2 (31–491). None of the patients had a BMI >40 kg/m2. Based on the diagnosis and at the surgeon's discretion, posterior bridging (n = 7) was carried out. On comparing the groups without vs. with bridging, no significant difference was seen in hernia length (=previous median laparotomy). Because of the significant difference in the defect width, there was a significant difference in the defect area. In the group of patients analysed here with bridging of the remnant posterior fascial defect, the median defect width was 24 cm. In almost all cases it was possible to reconstruct the linea alba in the anterior plane without a mesh. Only in one case was a non-absorbable mesh implanted for prosthetic replacement of the linea alba. Patients requiring additional bridging have significantly more postoperative complications. However, the length of the hospital stay is not significantly extended (**Table 2**).

The standard TAR mesh used had a median size of 1,200 cm^2. In the cases with posterior bridging (median mesh size 600 cm^2), the median size of the TAR mesh was increased approximately by exactly this area (1750 cm^2). For the technique presented here, the ratio of mesh size in the TAR plane to the defect size without bridging was 1,200 cm^2/177 cm^2 = 6.8, and with bridging it was 1750 cm^2/452 cm^2 = 3.8 (**Figure 3**). In total, posterior bridging was used in 7/22 (32%) of patients. While bilateral TAR was always performed in open medial hernia repair, bilateral TAR was performed only in 5/24 of cases in robotic TAR repair. In robotic TAR, posterior bridging was used in 3/24 (12.5%) of cases (unilateral TAR: n = 2, bilateral TAR: n = 1).

Robotic TAR was carried out in 24 patients (**Table 3**). The largest group consisted of patients with lateral incisional hernia. In 7 patients with parastomal hernia the stomata were: ileal

TABLE 2 | Perioperative outcome of open midline incisional hernia repair: ventral medial hernias with open TAR (n = 22).

	Ventral midline hernias (n = 22)		p
	TAR without bridging (n = 15)	TAR with bridging (n = 7)	
Age (years, Median, Min-Max)	62 (24–73)	66 (62–74)	n.s.
BMI (kg/m^2, Median, Min-Max)	28.7 (20.6–34.7)	31.3 (24.2–39.7)	n.s.
Defect width (cm, Median, Min-Max)	15 (8–21)	24 (10–25)	0.02
Proportion of W3 hernias (>10 cm)	87% (13/15)	100% (7/7)	n.s.
Defect length (cm, Median, Min-Max)	18 (5–30)	25 (20–25)	n.s.
Defect size (cm^2; ellipse formula: Median, Min-Max)	177 (31–396)	452 (157–491)	<0.01
Mesh bridging			
Posterior bridging		n = 7	
Additional anterior bridging		n = 1	
Size of posterior bridging mesh (cm^2; Median, Min-Max)		600 (400–1950)	
TAR mesh size (cm^2; rectangle formula: Median Min-Max)	1,200 (400–1750)	1750 (900–2,700)	0.05
Duration of surgery (minutes; Median, Min-Max)	139 (74–227)	222 (161–366)	<0.01
Hospital stay (days; Median, Min-Max)	6 (2–14)	10 (6–35)	n.s.
Morbidity	3/15	5/7	0.05
CD 0	n = 12	n = 2	
CD 1	n = 1	n = 1	
CD 2	n = 2	n = 2	
CD 3a	-	n = 1	
CD 3b	-	n = 1	
CD 4	-	-	
CD 5	-	-	

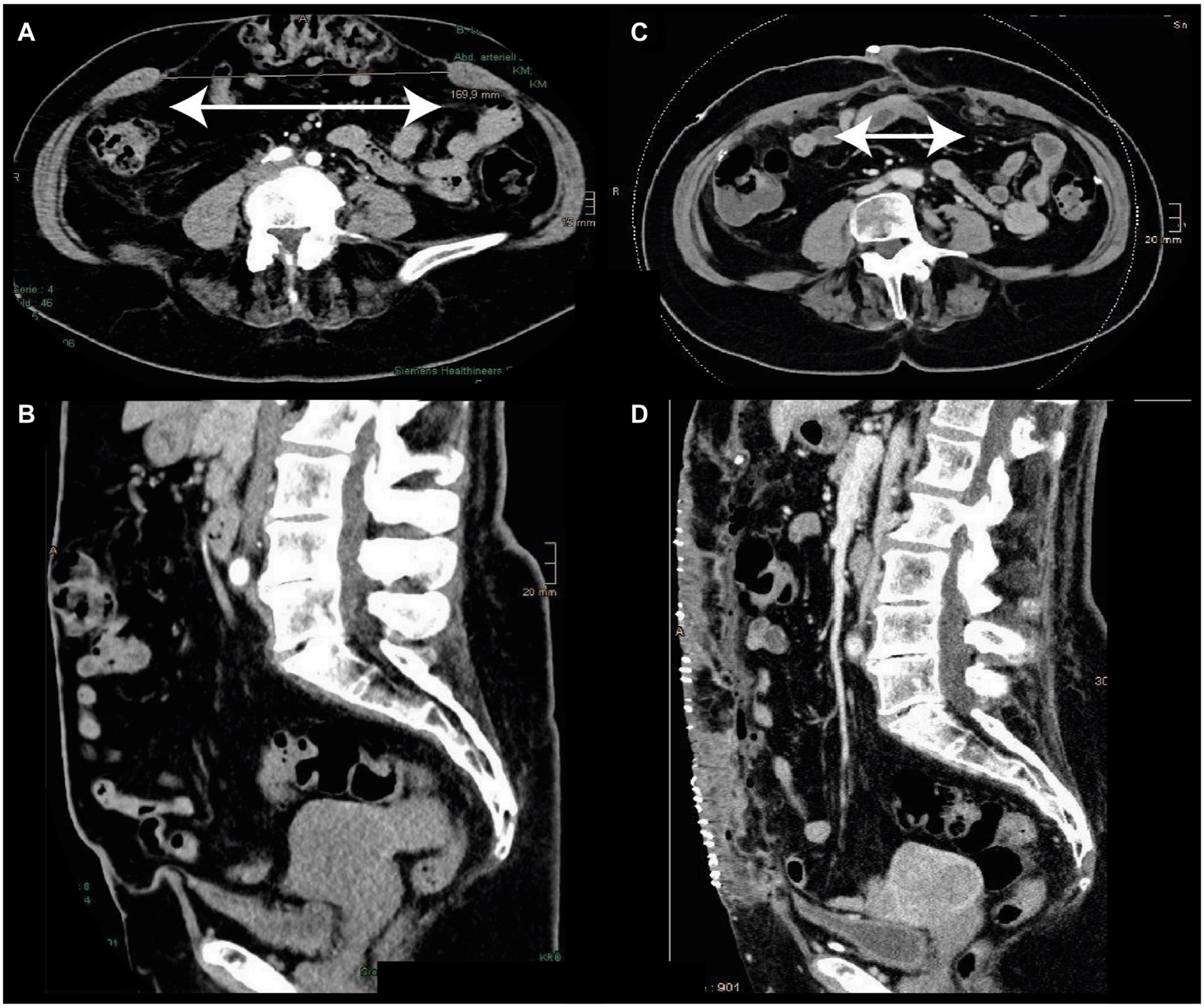

FIGURE 3 | Incisional hernia [pre: **(A,B)**] M1-M5, W3: 30 × 17 cm. Treatment with open TAR (45 × 30 cm) and underlying posterior bridging (30 × 20 cm) mesh. The postoperative linea alba had a width of 6 cm. The duration of surgery was 189 min, with discharge from the hospital on day 4.

conduit: n = 5, colostoma: n = 3, enterostoma: n = 1. The hernia orifices/defects of the lateral and parastomal hernias were markedly smaller than those of the medial hernias. TAR was indicated at this location because of the anatomical boundaries of the abdominal components regardless of size. In general, unilateral docking was sufficient for lateral and parastomal hernias (18/20). The greater effort needed for the Pauli procedure was reflected in a much longer duration of surgery. Despite the smaller defects, posterior bridging was also indicated here. As can be seen in **Figure 4**, with this technique it was possible to preserve the extraperitoneal space for a lateral hernia without any loss of area due to plication.

Subgroup analysis of medial hernias showed a pronounced procedural trend towards open TAR. The size of the defects and the number of meshes required were significantly larger. Nonetheless, the duration of surgery was shorter with open repair than with robotic repair regardless of bridging.

In the patient group analysed here, bridging was performed for very wide medial hernias to reconstruct the posterior plane. Posterior bridging was also indicated for lateral hernias in order to avoid area loss secondary to plication.

DISCUSSION

In addition to general optimisation of the patients (weight reduction and nicotine abstention [21]), there are individual concepts aimed at improving the local surgical conditions. Preoperative pneumoperitoneum (PPP) and preoperative Botox administration are well-known methods [22, 23]. Admittedly, PPP is restricted to specialist centres and is not yet established on a large

TABLE 3 | Robotic hernia surgery with TAR (n = 24), indications and outcome.

	Medial (n = 4)	Lateral (n = 13)	Pauli (n = 7)
Age	68 (60–74)	57 (27–82)	72 (57–80)
BMI	27 (24–37)	29 (21–48)	31 (22–37)
TAR bilateral	3	2	0
TAR unilateral	1	11	7
Ellipse defect size (Median, Min-Max)	47 (20–151)	16 (3–226)	13 (7–50)
Additional bridging?	1	1	1
Rectangle defect size (Median, Min-Max)	575 (216–900)	225 (100–900)	225 (196–400)
Duration of operation in minutes (Median, Min-Max)	255 (170–480)	143 (76–343)	242 (174–366)
Hospital stay in days (Median, Min-Max)	3 (2–6)	2 (2–8)	3 (1–9)
Morbidity	0/4	2/13	2/7
CD 0	n = 4	n = 11	n = 5
CD 1	-	-	n = 1
CD 2	-	n = 1	-
CD 3a	-	-	-
CD 3b	-	n = 1	-
CD 4	-	-	-
CD 5	-	-	n = 1

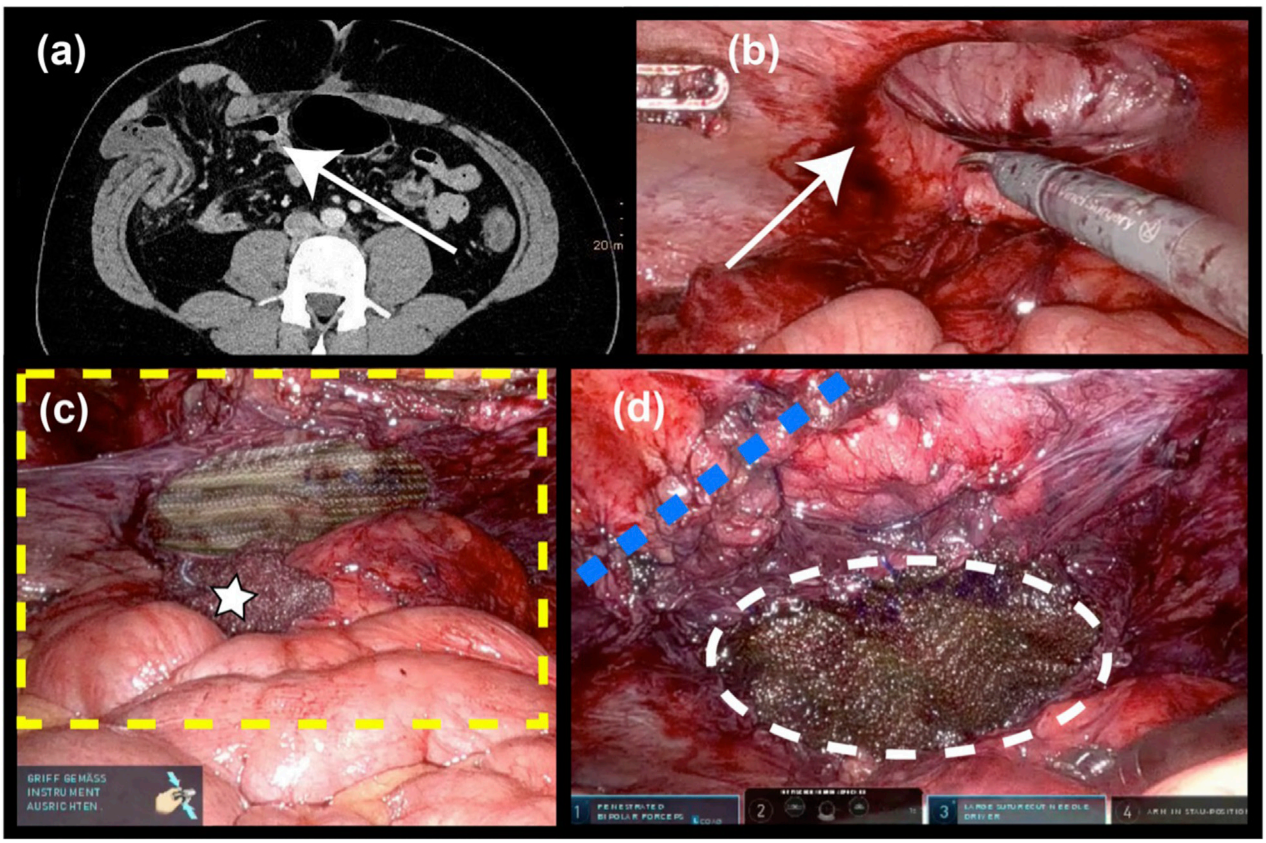

FIGURE 4 | Lateral incisional hernia (6 × 6 cm). **(A)** Preop. CT scan **(B)** after robotic ventral adhesiolysis **(C)** the yellow dotted line indicates the extent of the TAR mesh (17 × 14 cm) after posterior bridging with long-term absorbable mesh (10 × 7 cm); white star: intraoperatively used swab; **(D)** the blue dotted line denotes the running suture that closes access to the extraperitoneal space; and the white dotted line marks the posterior bridging mesh.

scale. The preoperative use of Botox is much more easily reproducible. Botox is administered once and surgical repair is carried out at the time of peak effect. However, in Germany at least, it is not approved for hernia surgery. A combination of the two techniques has also been described [24, 25]. Both treatment strategies implicate the preoperative detection of patients.

We are very confident in the TAR concept and have not used any additional pre-surgical treatments like Botox or PPP. Computed tomography is mandatory to detect those patients with a potential need for bridging. Once there are intraoperative indications that a tension-free posterior closure is not possible, we use a mesh for posterior bridging. In the study period this was done in 20% (10/50) of patients and in 28% of all patients undergoing open repair of a medial hernia. The performed comparison between bridging and non-bridging patients reflects the clinical routine in our clinics and could be considered a limitation of this single centre study. Further scientific research is necessary to learn more about the outcome of bridging patients in comparison with other treatment concepts for very large hernias.

Very different approaches are described in the literature for performing posterior bridging. Some publications give the names of the mesh materials used. There are also reports of fixation of the posterior plane to the omentum, assuming it is still available to that effect. The use of the hernia sac is another option. This appears to be optimal in terms of its biological properties and the fact that it is readily available. However, we believe that the hernia sac should, always be left in place at the start of the repair so that it can be used here for the final reconstruction of the linea alba. Although the literature also reports on anterior mesh coverage with subcutaneous and connective tissue [5, 10, 26], based on our experience, the hernia sac tissue provides the most consistent stability. If the quality of the suture bed is inadequate, anterior bridging with a non-absorbable mesh may be advisable. In robotic repair of medial incisional hernias the hernia sac tissue is also left in the anterior plane and later integrated into the anterior suture. We have consistently applied this technique in open surgery.

We deliberately refrain from a stepwise forced approximation of the left and right rectus fascia, attempting instead to achieve the physiological reconstruction of the linea alba. From clinical observation, we are not aware of any disadvantages. So far, we do not have follow-up data on our patients. To our knowledge there are no published studies reporting on the ideal width of a reconstructed linea alba in relation to TAR repair. The low rate of patients with severe complications in the group reported here appears to confirm the benefits of the described procedure.

A much-feared and life-threatening complication of hernia surgery is abdominal compartment syndrome [27–30]. It is caused by an imbalance between the space needed by the abdominal organs and the space available in the newly created abdominal cavity. Previous surgical concepts aimed at countering this included, apart from omentum resection, even bowel resection. The focus here is on abdominal wall-related treatment concepts. The most widely established of these is the anterior [31] and posterior [1] component separation. A newer method is biochemical component separation with Botox, possibly in combination with progressive pneumoperitoneum [32, 33]. The fasciotens system (Dahlhausen, Cologne, Germany) is another innovative method designed for midline reconstruction through intraoperative traction [34]. We believe that tension-free reconstruction and extraperitoneal placement of a non-absorbable mesh with sufficient overlap are the cornerstones of optimal hernia repair [8]. With the technique presented here, the TAR mesh covers the defect by a factor of 6.8 in cases without bridging and by a factor of 3.8 in cases with bridging.

Reconstruction of the linea alba may take place as a result of impaired wound healing. For this reason, further medialisation of the anterior plane could make sense. A combination of anterior and posterior component separation would represent a major step forward [20]. We believe that the associated weakening of the lateral abdominal wall is a disadvantage that has not been properly investigated so far. With this in mind, we feel that accepting a mesh-reinforced rectus diastasis is the best compromise if low-risk reconstruction is attempted. Further studies should be carried out to investigate the functional outcomes of patients in the long term. Perioperative observations do not point to any abnormalities. Another option could be the preoperative application of Botox to the anterior muscle layer. This would theoretically facilitate the reconstruction of the linea alba. However, we do not expect any effect on the need for posterior bridging in our technique as the medial extent of the posterior layer is mainly influenced by the preservation of the hernia sac in the anterior layer.

For lateral and parastomal hernias unilateral TAR is generally sufficient to generate an extraperitoneal space with adequate mesh overlap. As mentioned above, a defect in the size of the hernia orifice may occur in the posterior plane. Bridging in this setting helps to preserve the extraperitoneal mesh bed (landing zone) as necessary for the TAR mesh. A possible technical alternative would be the use of coated meshes. However, based on our observations, it is easier to begin with the reconstruction of the posterior plane and then focus on the optimal placement of the TAR mesh. In the study period presented here, there were no patients with loss of domain at this location. We therefore did not include theoretical considerations in this publication.

SUMMARY

TAR is an important surgical tool in the repair of ventral and parastomal hernias. It offers unique opportunities through the tension-free placement of meshes with adequate overlap. Posterior bridging is a useful adjunct that can be used here depending on the intraoperative findings. There is no need for the preoperative selection of patients for special pretreatment. Therefore, this concept offers very high flexibility in the routine treatment of these patients.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

Only cases of routine hernia surgery were documented in the Herniamed Registry and all patients have signed a special informed consent declaration agreeing to participate. The

Herniamed Registry has ethical approval (BASEC Nr. 2016-00123; 287/2017 BO2; F-2022-111).

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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The Madrid Posterior Component Separation: An Anatomical Approach for Effective Reconstruction of Complex Midline Hernias

Marcello De Luca[1,2]*, *Manuel Medina Pedrique*[2,3], *Sara Morejon Ruiz*[2,3], *Joaquin M. Munoz-Rodriguez*[4], *Alvaro Robin Valle de Lersundi*[2,3], *Javier Lopez-Monclus*[4], *Luis Alberto Blázquez Hernando*[5] and *Miguel Angel Garcia-Urena*[2,3]

[1]UOC Chirurgia Generale Oncologica e Mininvasiva, Azienda Ospedaliera Universitaria, University of Naples Federico II, Naples, Campania, Italy, [2]Servicio de Cirugía General y Aparato Digestivo, Hospital Universitario del Henares, Fundación Investigación e Innovación Biomédica H. Santa Sofía- H del Henares, Madrid, Spain, [3]Grupo de Investigación de Pared Abdominal Compleja, Universidad Francisco de Vitoria, Madrid, Spain, [4]Servicio de Cirugía General y Aparato Digestivo, Hospital Universitario Puerta de HIerro, Madrid, Spain, [5]Servicio de Cirugía General y Aparato Digestivo, Hospital Universitario Ramón y Cajal, Madrid, Spain

Introduction: In recent years, Posterior Component Separation (PCS) with the Madrid modification (Madrid PCS) has emerged as a surgical technique. This modification is believed to enhance the dissection of anatomical structures, offering several advantages. The study aims to present a detailed description of this surgical technique and to analyse the outcomes in a large cohort of patients.

Materials and Methods: This study included all patients who underwent the repair of midline incisional hernias, with or without other abdominal wall defects. Data from patients at three different centres specialising in abdominal wall reconstruction was analysed. All patients underwent the Madrid PCS, and several variables, such as demographics, perioperative details, postoperative complications, and recurrences, were assessed.

Results: Between January 2015 and June 2023, a total of 223 patients underwent the Madrid PCS. The mean age was 63.4 years, with a mean BMI of 33.3 kg/m^2 (range 23–40). According to the EHS classification, 139 patients had a midline incisional hernia, and 84 had a midline incisional hernia with a concomitant lateral incisional hernia. According to the Ventral Hernia Working Group (VHWG) classification, 177 (79.4%) patients had grade 2 and 3 hernias. In total, 201 patients (90.1%) were ASA II and III. The Carolinas Equation for Determining Associated Risks (CeDAR) was calculated preoperatively, resulting in 150 (67.3%) patients with a score between 30% and 60%. A total of 105 patients (48.4%) had previously undergone abdominal wall repair surgery. There were 93 (41.7%) surgical site occurrences (SSO), 36 (16.1%) surgical site infections (SSI), including 23 (10.3%) superficial and 7 (3.1%) deep infections, and 6 (2.7%) organ/space infections. Four (1.9%) recurrences were assessed by CT scan with an average follow-up of 23.9 months (range 6–74).

Conclusion: The Madrid PCS appears to be safe and effective, yielding excellent long-term results despite the complexity of abdominal wall defects. A profound understanding

***Correspondence**
Marcello De Luca,
cellodeluca@gmail.com

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of the anatomy is crucial for optimal outcomes. The Madrid modification contributes to facilitating a complete retromuscular preperitoneal repair without incision of the transversus abdominis. The extensive abdominal wall retromuscular dissection obtained enables the placement of very large meshes with minimal fixation.

Keywords: Madrid APPROACH, Madrid posterior component separation, Madrid TAR, posterior component separation, posterior rectus sheath release

INTRODUCTION

All patients undergoing abdominal surgery with a laparotomic incision are exposed to the risk of developing an incisional hernia (IH) [1–3]. The treatment of large IH, especially in complex abdominal cases, has been and continues to be a significant challenge for surgeons [4]. Over the past decades, various techniques have been described based on the prosthetic

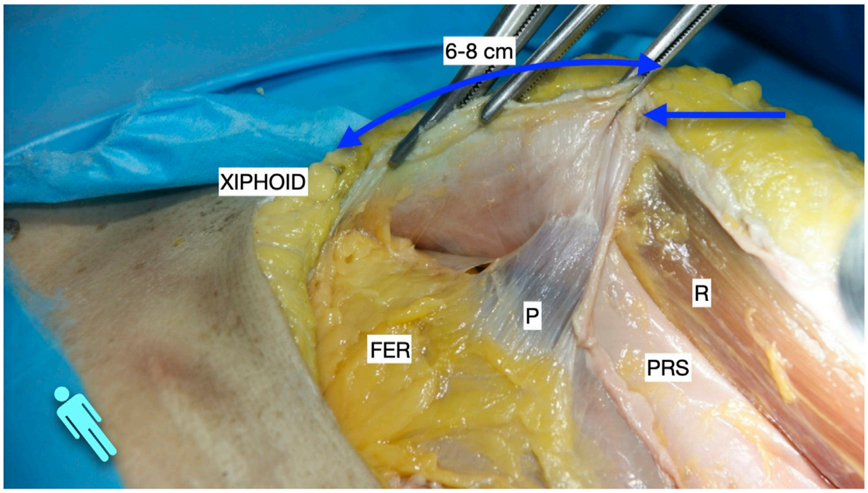

FIGURE 1 | Image of dissection of the preperitoneal pathway in the epigastric area of a defrosted cadaver. An incomplete Rives was performed with preservation of the cranial insertion of the PRS. The blue arrow shows the “incomplete” Rives where the medial incision was stopped at the PRS. The dissection was made leaving the fatty epigastric rhomboid over the peritoneum. The fibres of the TA muscle can be discerned through the fascia transversalis. R, rectus muscle; P, peritoneum; PRS, posterior rectus sheath; FER, fatty epigastric rhomboid; FT, fascia transversalis; A, ambivium; TA, transversus abdominis.

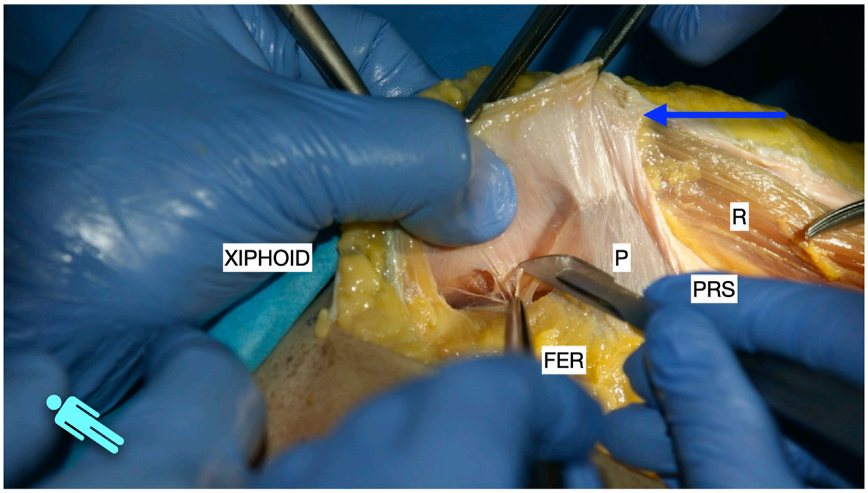

FIGURE 2 | Image of dissection of the preperitoneal pathway in the epigastric area of a defrosted cadaver. Lateral to the FER, the dissection had to be changed to a pre-transversalis plane. The image shows where to start to enter pre-transversalis fascia.

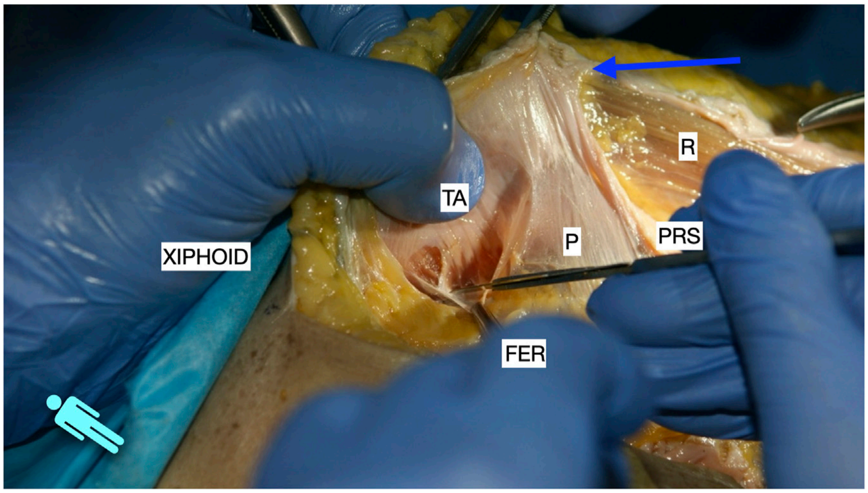

FIGURE 3 | Image of dissection of the preperitoneal pathway in the epigastric area of a defrosted cadaver. The fascia transversalis was left on the floor of the dissection and the TA muscle is shown.

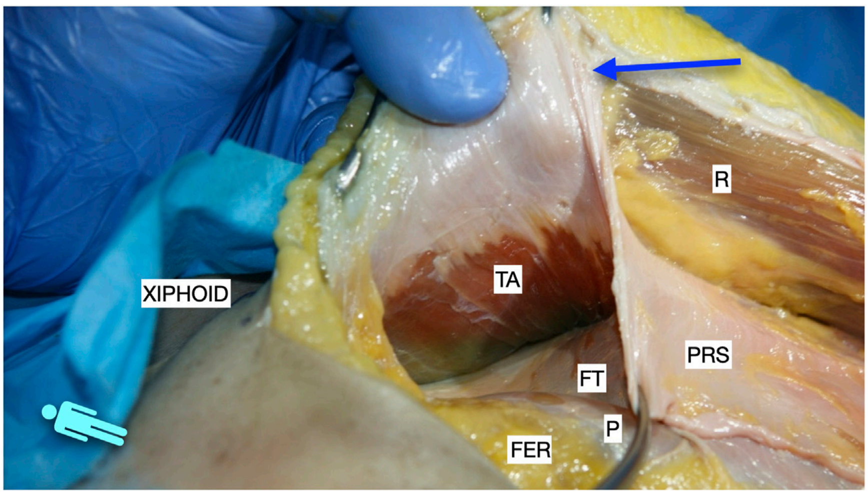

FIGURE 4 | Image of dissection of the preperitoneal pathway in the epigastric area of a defrosted cadaver. The pre-transversalis plane was developed posterior to the PRS, without incising the TA muscle fibres.

material reinforcement and the anatomical plane used, each attempting to provide advantages over previous techniques.

The use of the retro-muscular and preperitoneal planes, described by Rives and Stoppa, allows for the reconstruction of the abdominal wall using a non-absorbable prosthetic material, positioning it without direct contact with the intestinal loops and avoiding subcutaneous dissection [5,6]. However, this technique cannot be used for larger midline defects that require dissection beyond the *linea semilunaris* or for lateral IH.

To overcome this limitation, Carbonell devised the posterior component separation (PCS) in 2008, and Novitsky modified it in 2012 by introducing the Transversus Abdominis Release (TAR) [7,8]. While both, anterior and posterior component separation are based on the release of one of the lateral abdominal wall muscles, Heniford proposed to enter the preperitoneal space without adding any muscular release [9,10]. The goal of all these techniques remained essentially the same. The researchers aimed to obtain an extensive dissection in the retro-muscular and preperitoneal planes allowing the placement of a large mesh as a closure reinforcement.

Subsequently, after mastering the technique, improving the knowledge of prosthetic materials, and conducting anatomical studies on cadavers, we suggested some modifications to the original TAR [11,12]. The combination of permanent and absorbable prosthetic materials has been defined as the

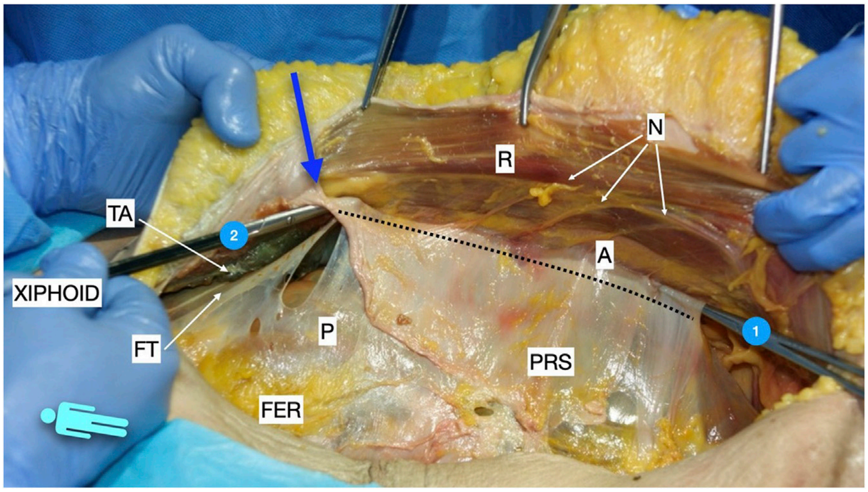

FIGURE 5 | Picture taken in a defrosted cadaver to show the pathways of the preperitoneal space before performing the Madrid PCS. 1: preperitoneal pathway in the Bogros space; 2: preperitoneal pathway in the epigastric area in a pre-transversalis layer. The blue arrow shows the "incomplete Rives" where the medial incision was stopped at the PRS. The dotted line shows the lateral incision at the posterior rectus sheath in the Madrid PCS. FER, fatty epigastric rhomboid; R, rectus muscle; PRS, posterior rectus sheath; P, peritoneum; A, ambivium; N, terminal branches of intercostal nerves; FT, fascia transversalis; TA, transversus abdominis.

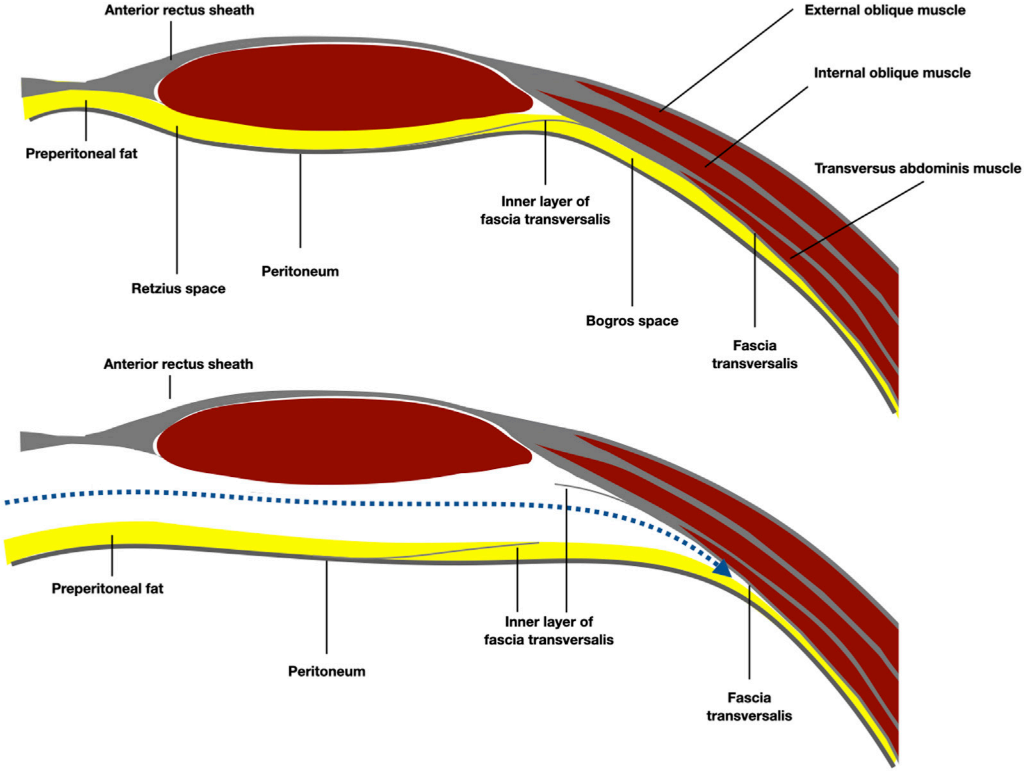

FIGURE 6 | Schematic representation of the anatomy of the Bogros space, under the arcuate line. The preperitoneal plane was developed preperitoneal over the fatty trident.

"Madrid APPROACH" (Absorbable Posterior Reinforcement of Permanent mesh Of A Complex Hernia) [13], and the preservation of the transversus abdominis (TA) muscle fibres through the release of the posterior rectus sheath (PRS), named the "Madrid modification" [14], has been introduced as an effective and safe technique [11].

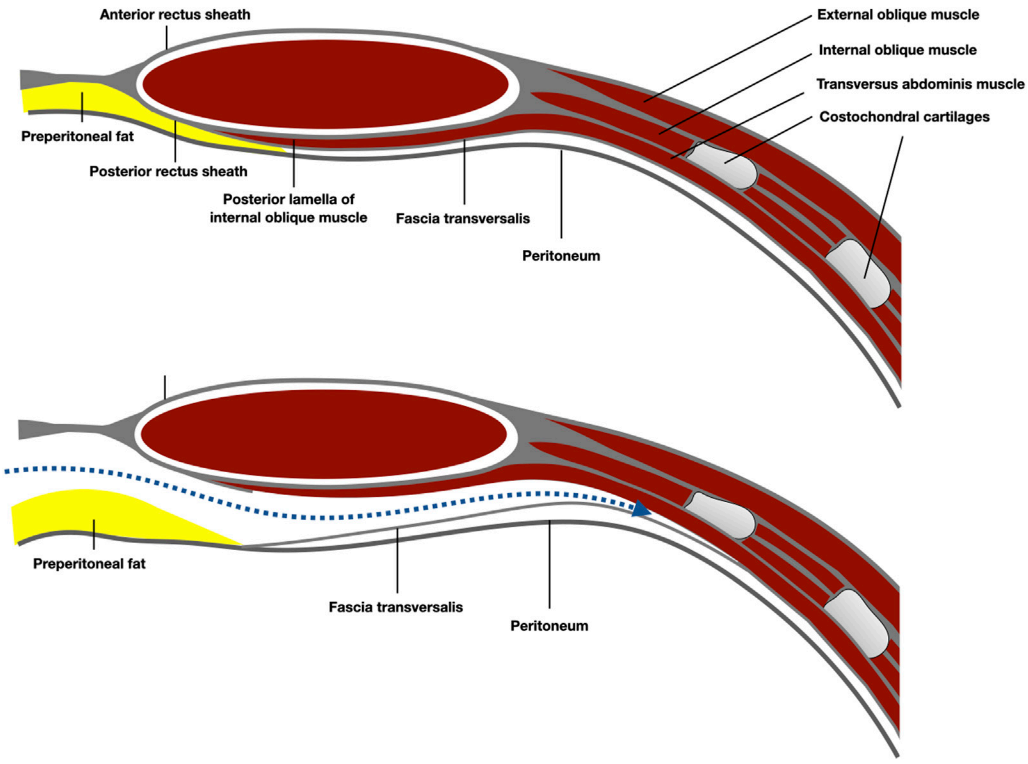

FIGURE 7 | Schematic representation of the anatomy of the epigastric area and the preperitoneal plane developed pre-transversally.

The aim of this multicentre study is to provide a detailed description of the Madrid posterior component separation (Madrid PCS), including an analysis of the results from a large cohort of patients to update previously published results.

MATERIALS AND METHODS

From January 2015 to June 2023, all coecutive patients undergoing abdominal wall surgery for midline incisional hernias were enrolled. The inclusion criterion was the use of the Madrid PCS technique; any other form of abdominal wall reconstruction for midline IH was excluded. This study involved three specialised abdominal wall surgery centres located in Madrid. Patients were prospectively entered into a shared database on Redcap.

Demographic variables were collected for all patients, including age, sex, BMI, comorbidities, CeDAR (Carolinas Equation for Determining Associated Risk), ASA score, type of previous surgery and the number of previous attempts at abdominal wall reconstruction. The characteristics of midline IH were recorded according to the EHS classification (EHS M1-M5) [15], focusing on size and location. Additionally, all midline IH associated with lateral defects (EHS L1-L4) or with inguinal hernia were also recorded. Finally, variables related to bridging and reinsertion of the TA muscle were documented.

Postoperative variables, including systemic or local surgical complications (SSO, SSI, and SSOPI), were classified according to the Clavien-Dindo Classification (CDC) [16]. Intensive care unit stay, length of hospitalisation and readmission were also analysed. Clinical follow-up was conducted at 6 weeks, 3 months, 6 months, and then annually. A CT scan was performed when clinical examination raised doubt about a recurrence. Late complications, such as chronic seroma, chronic prosthesis infection, chronic pain, bulging, recurrence, intestinal obstruction, and mortality, were recorded.

This study was reported in line with the STROBE statement [17]. The study was approved by the Research Ethics Committee of Francisco de Vitoria University (39/2019) and the Institutional Review Board (37/2022). The patients provided written informed consent to participate in this study.

Surgical Technique

All patients followed a standardised preoperative optimisation programme that comprised endocrinological and nutritional assessments, respiratory physiotherapy, and abstinence from smoking for a minimum of 1 month prior to surgery. While weight loss was strongly recommended, it was not mandatory. Since 2018, preoperative botulinum toxin has been regularly administered for defects greater than 9 cm, and pneumoperitoneum has been employed in cases involving loss of domain.

TABLE 1 | Demographics.

Variable	N (%)
Age, years	63.39 (range 32–87)
Sex	137 (61.4%) male; 86 (38.6%) female
BMI, kg/m^2	33.25 (range 23–40)
ASA median	2
I	17 (7.62%)
II	123 (55.16%)
III	78 (34.98%)
IV	5 (2.24%)
CeDAR mean	36.89 (range 2–91)
<30%	54 (24.22%)
30%–60%	150 (67.27%)
>60%	19 (8.52%)
Comorbidities	
Any	189 (84.75%)
Smocking	48 (21.53%) daily; 60 (26.91%) ex-smocker
Anticoagulation	45 (20.18%)
Diabetes	54 (24.22%)
Immunosuppression	24 (10.76%)
Lung disease	48 (21.53%)
Hypertension	109 (48.88%)
Neoplasia	72 (32.29%)
Previous abdominal wall hernia operation	105 (48.39%)
Number of previous attempts of IH repair, mean	2.33 (range 0–13)
Cause of first surgery	
Hepatobiliopancreatic	19 (8.52%)
Digestive tube	114 (51.12%)
Gynaecologic	23 (10.31%)
Abdominal wall	28 (12.56%)
Urologic	22 (9.87%)
Cardiac	3 (1.35%)
Post-trauma	9 (4.04%)
Vascular	2 (0.89%)
Orthopaedic	1 (0.45%)
Others	2 (0.89%)

The procedure outlined below is the one we are currently following.

The patient is placed in the supine position and covered with a skin drape to prevent direct contact of the prosthetic materials with the skin. The previous scar is removed, and unless it is particularly extensive, a 15 cm incision is sufficient for optimal exposure of the surgical field. Panniculectomy is performed in those cases with very redundant skin and subcutaneous tissue.

Subcutaneous dissection does not extend beyond the hernia defect and the sac is opened as soon as possible longitudinally. The two flaps are preserved until the end of the procedure, determining in advance for each half of the sac which will be left attached to the PRS to help close the posterior layer, or which will be left attached to the anterior rectus sheath to cover the mesh in case of a potential bridge [18,19]. Extensive adhesiolysis is performed throughout the cavity as far as the anterior axillary line and a coloured cloth is placed intraabdominally to protect the intestinal bowels.

The procedure continues with the execution of what we consider an "incomplete Rives" technique. Systematically, the dissection begins with lateral dissection of the retromuscular space, followed by bilateral caudal and then epigastric dissection. Laterally, the entire retromuscular space is dissected until the merge of the neurovascular bundles, which are preserved. This lateral limit has recently been called the "ambivium" [20]. Once we have dissected both lateral retromuscular spaces, then inferiorly, beyond the arcuate line and taking advantage of the distribution of preperitoneal fat [21], dissection continues by dissecting the Retzius space in the midline, the Bogros spaces laterally and exposing Cooper's ligaments. Attention is given to the epigastric vessels, which, along with the surrounding adipose tissue, are preserved. In the case of an M4 or M5 IH, the spermatic vessels and vas deferens (or round ligament) are parietalised as shown by Stoppa [6].

Cranially, the medial incision on the PRS stops 7-8 cm from the xiphoid, preserving the anatomical insertion of the PRS on the costal cartilages [**Figure 1**]. In this epigastric region, the dissection continues laterally and cranially into the preperitoneal space, leaving the lateral fatty tissue of the epigastric rhomboid fat over the peritoneum and navigating just below the "white" PRS. We do both sides first and then, we enter the subxiphoid space. Two centimetres outside the midline, the preperitoneal plane is changed to a pre-transversalis plane under the fibres of the TA muscle [**Figures 2–4**]. Cranially, the dissection under the fibres of the TA muscle is followed by a pre-facia diaphragmatic plane, under the fibres of the diaphragm. Anatomical findings have shown that, at this level, the pre-transversalis fascia and pre-diaphragmatic fascia planes are preferable to the preperitoneal one. The reason is that here we lose the protection of the preperitoneal fat distribution, with the risk of peritoneal tears. At this phase, the two planes obtained bilaterally converge in the subxiphoid space. Here, a significant adipose pad is systematically left attached to the xiphoid process and the dissection continues beneath it, over the peritoneum. This fatty pad has previously been referred to as the fatty triangle [22]. One constant vessel runs on both sides of this fatty pad, which can be easily controlled. The dissection continues cranially up to the central tendon of the diaphragm. Following the dome shape of the diaphragm is crucial to avoid iatrogenic Morgagni hernias. Particular attention must be paid to the constant anatomical insertion of the fibres of the diaphragm on the PRS. When we reach the central tendon, the fascia diaphragmatica fuses the tendon and our layer becomes again the preperitoneal plane and, therefore, is easy to tear. This entire epigastric preperitoneal dissection entered the plane under the TA muscle in both upper quadrants.

Therefore, the procedure continues with the PRS release. To enter the preperitoneal Bogros space, some fibres of the inner fascia transversalis must be torn or broken. Once in the Bogros space, the arcuate line is identified and with the assistance of a finger, a blunt dissection is performed to access the lateral preperitoneal space. By pushing the visceral sac downward and medially, the peritoneal sac can be separated bluntly from the PRS. A down to up PRS release is performed to join the two dissected preperitoneal pathways: the epigastric pre-transversalis and the Bogros preperitoneal one [**Figure 5**]. Once the first centimetres are cut 0.5–1 cm medial to the ambivium, we carefully dissect laterally and

TABLE 2 | Characteristics of IH.

Variable	N(%)
Midline defect	139 (62.33%)
Midline + lateral defect	84 (37.67%)
EHS Classification	
M1	3 (1.35%)
M2	7 (3.14%)
M3	14 (6.28%)
M4	2 (0.89%)
M5	1 (0.45%)
M1-2	2 (0.89%)
M1-3	32 (14.35%)
M1-4	19 (8.52%)
M1-5	59 (26.46%)
M2-3	8 (3.59%)
M2-4	29 (13.01%)
M2-5	14 (6.28%)
M3-4	1 (0.45%)
M3-5	28 (12.56%)
M4-5	4 (1.79%)
L1 SUBCOSTAL	21 (9.42%)
L2 FLANK	15 (6.73%)
L3 ILIAC	38 (17.04%)
L4 LUMBAR	10 (4.48%)
Slater Classification	
Minor	12 (5.38%)
Moderate	125 (56.05%)
Major	86 (38.57%)
VHWG Classification	
Grade 1	33 (14.79%)
Grade 2	126 (56.5%)
Grade 3	51 (22.87%)
Grade 4	13 (5.83%)
Wound Classification	
Clean	157 (70.4%)
Clean-Contaminated	44 (19.73%)
Contaminated	13 (5.83%)
Dirty	9 (4.04%)
VHSS Classification	
Stage 1	50 (22.42%)
Stage 2	119 (53.36%)
Stage 3	54 (24.22%)

TABLE 3 | Operative data.

Variable	N (%)
Elective surgery	222 (99.55%)
Emergency surgery	1 (0.45%)
Size of defect of anterior layer	
Horizontal, cm, mean	12.68 (range 4–30)
Vertical, cm, mean	15.56 (range 5–40)
Surgical technique	
Unilateral Madrid PCS	35 (15.7%)
Bilateral Madrid PCS	188 (84.31%)
Bridging of posterior layer[a]	12 (5.38%)
Bridging of anterior layer[b]	76 (34.08%)
Associated surgery to IH repair	179 (80.27%)
Adhesiolysis	126 (56.5%)
Omentum resection	2 (0.89%)
Intestinal resection	9 (4.04%)
Suture of bowel	13 (5.83%)
Intestinal transit reconstruction	7 (3.14%)
Ileostomy closure	1 (0.45%)
Other abdominal operation	21 (9.42%)
Panniculectomy	47 (21.08%)
None	44 (19.73%)
Reimplant of TA	43 (19.29%)
Drains	
Over the mesh	149 (66.82%)
Subcutaneous and over the mesh	72 (32.29%)
Subcutaneous	1 (0.45%)
None	1 (0.45%)
Mean operative time, min	235 (range 75–540)

[a]*Impossibility to completely close peritoneum and/or posterior rectus sheaths.*
[b]*Impossibility to completely close linea alba (borders of anterior rectus sheaths).*

cranially with gentle manoeuvres on the preperitoneal space under the TA muscle to release the tension on the peritoneum. The down to up PRS release advanced cranially parallel to the ambivium up to the umbilical area, always combining the incision with the previous lateral preperitoneal dissection. Subsequently, the direction becomes oblique to the midline to meet with the point where we stopped the medial incision on the PRS in the epigastric area. After complete PRS release, the preperitoneal dissection continues laterally until the identification of the tip of the twelfth rib cranially, the psoas muscles, and the posterior iliac crest caudally. At this level, it is common to coagulate the constant deep circumflex vessels arising from the iliopsoas muscle. The dissection plane in the lower two-thirds of the abdomen is preperitoneal [**Figure 6**], while in the upper third, as mentioned earlier, it is pre-transversalis fascia and pre-diaphragmatic fascia [**Figure 7**]. A horizontal line of fascia transversalis can always be observed between the upper third pre-transversalis and the two lower thirds preperitoneal.

Finally, the abdominal wall reconstruction is carried out. The PRS, along with the peritoneum and the preserved hemi-sac, is used to close the posterior wall in the midline with a continuous slowly-absorbable 00 or 000 monofilament suture. If the posterior wall cannot be closed, a bridge repair using a piece of absorbable mesh is made. All openings larger than 0.5 cm are closed. Subsequently, a 20 × 30 cm bioabsorbable mesh (GORE® BIO-A® Tissue Reinforcement, WL Gore & Associates, Inc. Flagstaff, AZ, United States) is positioned without fixation as a reinforcement of the posterior layer. This mesh is tailored to fit the shape of the inguinal region. Above it, in the same retromuscular-preperitoneal space, an extensive 50 × 50 cm macroporous polypropylene mesh (Bulevb®, Dipro Medical Devices SRL, Torino, Italy) is placed and fixed only to Cooper's ligaments with long-term absorbable sutures. The mesh is placed in a diamond shape for larger patients. In M4-M5 defects, or in the presence of inguinal hernias, this mesh is given the Stoppa configuration to protect the myopectineal areas [6].

Subsequently, anaesthesia of the muscle plane is performed by infiltrating levobupivacaine between the internal oblique and TA muscles. In younger patients or those who are physically active,

TABLE 4 | Postoperative complications.

Variable	N (%)	Clavien-Dindo >1
Any complication	84 (37.67%)	
Seroma	38 (17.04%)	
- requiring procedural intervention	30 (13.45%)	30 IIIa
Hematoma	12 (5.38%)	
- requiring procedural intervention	3 (1.35%)	2 IIIa; 1 IIIb
SSI	36 (16.14%)	7 II; 28 IIIa; 1 IIIb
- superficial	23 (10.31%)	7 II; 16 IIIa
- organ/space	6 (2.69%)	6 IIIa
- deep	7 (3.14%)	6 IIIa; 1 IIIb
Wound dehiscence	7 (3.14%)	
Abdominal complications		
Ileus	22 (9.87%)	
Intestinal obstruction	2 (0.89%)	
Fistula	10 (4.48%)	7 IIa; 2 IIIa; 1 IIIb
Intra-abdominal hypertension (IAP) > 11 mmHg	9 (4.04%)	9 IVa
IAP >20 mmHg + organ failure	1 (0.45%)	1 IVa
Systemic complications		
Urinary infection	10 (4.48%)	1 II
Venous line infection	6 (2.69%)	4 II; 2 IIIa
Respiratory failure	16 (7.18%)	5 II; 3 IVa; 4 IVb
Pneumonia	9 (4.04%)	5 II; 1 IIIa; 2 IVb
Cardiac complication	13 (5.83%)	8 II; 3 IVb
Intensive Care Unit stay	89 (39.91%)	
Lenght of hospital stay, day, mean	10.92 (range 1–98)	
Readmission	19 (8.52%)	
Follow-up	199 (89.24%)	
Lost to follow-up	10 (4.48%)	
Deceased due to unrelated causes	14 (6.28%)	
Duration of follow-up, day, mean	718 (range 180–2,216)	
Late SSI		
- superficial	0	
- deep wound infection	2 (0.94%)	2 IIIa
- mesh infection	5 (2.35%)	5 IIIb
Chronic seroma	6 (2.69%)	5 IIIa; 1 IIIb
Chronic pain		
- occasionally need for pain treatment	7 (3.29%)	
- daily pain treatment	2 (0.94%)	
- discomfort	6 (2.82%)	
Bulging		
- symptomatic	2 (0.94%)	
- asymptomatic	14 (6.57%)	
Foreign body reaction	2 (0.89%)	
Recurrence	4 (1.88%)	2 IIIb

we usually reinsert the lateral border of the PRS cut to the mesh with running sutures of slowly-absorbable material. If closure of the anterior layer is not possible, the borders of the bridge are sutured with running sutures and covered with a peritoneal flap. In bridges larger than 4 cm in width, we suture an additional sheet of mesh to the bridged area as an inlay. At least one suction drainage is always placed in the retromuscular-periprosthetic space.

Statistics

The description of variables and statistical analysis were conducted using Microsoft® Excel® for Microsoft 365 MSO (Version 2,312 Build 16.0.17126.20132) 64-bit. Quantitative variables were expressed as mean and range, while categorical variables were presented as absolute frequencies and percentages.

RESULTS

A total of 223 patients underwent surgery, including 137 men (61.4%) and 86 women (38.6%). The mean age was 63.4 years (range 32–87). A total of 100 patients had a BMI >30 kg/m^2 with a mean of 33.3 (range 23–40). In total, 84.8% of patients (n = 189) had at least one comorbidity, with the most common being arterial hypertension (48.9%), a history of oncological pathology (32.3%), and diabetes (24.2%). A 21.5% of patients were active smokers, while 26.9% had quit smoking less than 12 months before. The mean CeDAR was 36.9%, with 150 patients (67.3%) falling between 30% and 60%. The median ASA score was 2, with the majority of patients being ASA2 and ASA3, 123 (55.2%) and 78 (35%), respectively. **Table 1** shows the origin of IH. Of the total enrolled patients, 105 (48.4%)

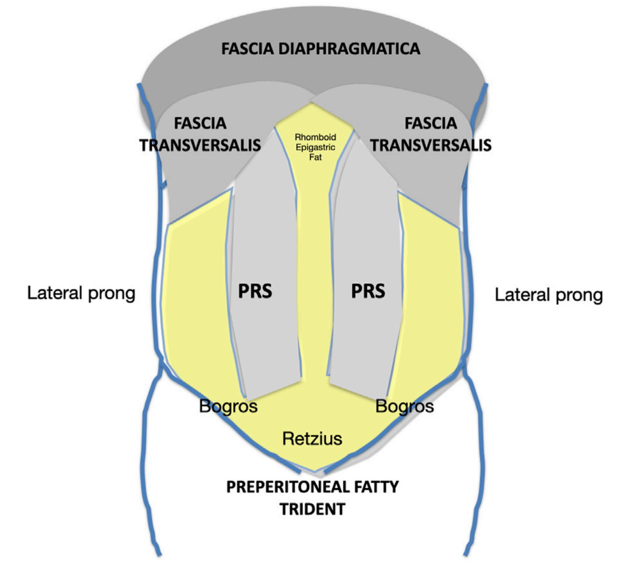

FIGURE 8 | Schematic of the retromuscular and preperitoneal space dissected according to the Madrid PCS. PRS, Posterior rectus sheath.

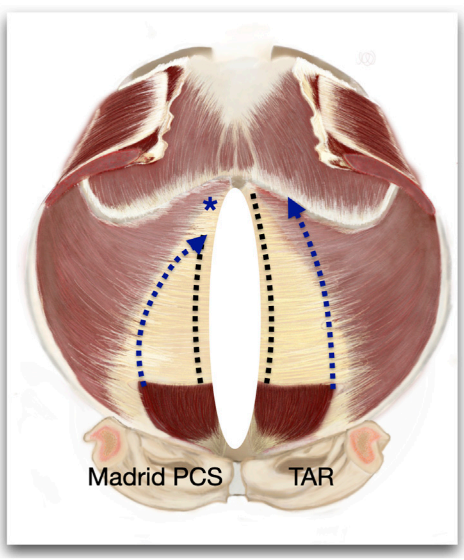

FIGURE 9 | Figure of an internal view of the abdominal wall to represent the differences between the Madrid PCS and TAR. * Shows the preservation of the cranial insertion of the PRS.

had already undergone abdominal wall repair, with a mean of 2.3 attempts (range 0–13) [**Table 1**].

Of the 223 patients, 139 (62.3%) had a pure midline defect, while 84 (37.7%) also presented with an associated lateral defect, as illustrated in **Table 2**. The midline defects were always W3, whereas the cases in which a lateral defect was associated with the midline ones were W1 in 21 cases (24.7%), W2 in 60 cases (71.8%), and W3 in 3 cases (3.6%). The surgical approach included 35 (15.7%) unilateral Madrid PCS and 188 (84.3%) bilateral Madrid PCS procedures. Operative variables are detailed in **Table 3**, indicating that closure of the posterior layer was consistently achieved, except in 12 patients (5.4%). Bridging of the anterior layer was performed in 76 patients (34.1%), and reinsertion of the transversus abdominis (TA) muscle was conducted in 43 patients (19.3%). The mean operative time was 235.3 min (range 75–540 min).

A total of 139 patients (62.3%) did not experience any postoperative complications [**Table 4**]. Of the complications reported in 38 patients (17%), postoperative seroma development was noted in 30 patients (13.5%), requiring procedural intervention. Additionally, 12 patients (5.4%) had a postoperative hematoma, with 3 cases (1.4%) necessitating operative management. Surgical site infections (SSI) occurred in 36 patients (16.1%), with 23 (10.3%) superficial, 7 (3.1%) deep, and 6 (2.7%) organ/space infections. Of these, only 1 patient (0.5%) required removal of the infected mesh. The mean length of hospital stay was 10.9 days (range 1–98 days).

A total of 199 patients (89.24%) completed at least a 6-month clinical follow-up [**Table 4**]. In 4 cases (1.8%), clinical follow-up was not feasible, necessitating a telephone interview. The mean follow-up duration was 718 days (range 180–2,216 days). During follow-up, 14 patients (6.3%) died due to causes unrelated to surgery, while an additional 10 patients (4.5%) did not attend regular check-ups. Late complications included 7 patients (3.3%) experiencing deep wound or prosthesis infections, requiring surgery in 5 cases (2.4%). Chronic seroma developed in 6 patients (2.7%), and a foreign body reaction was observed in only 2 patients (0.9%). Chronic pain was reported by 15 patients (7%), with 2 subjects (0.9%) requiring daily pain treatment. Patients with uncertain clinical signs of recurrence underwent a follow-up CT scan, which revealed a total of 4 recurrences (1.9%).

DISCUSSION

The PCS with TAR is a technique described to repair large midline hernias where the Rives-Stoppa technique is insufficient for abdominal wall reconstruction. This technique, as outlined by Novitsky et al, allows for the successful treatment of large IH, requiring extensive dissection, while maintaining the advantage of using a permanent prosthesis in the sublay position [7]. The results reported in their case series are very favourable, despite the fact that approximately 90% of the patients had a grade 2-3 IH based on the modified hernia grading scale and a median hernia width of 15 cm. In a subsequent study, this group reported a low number of recurrences (3.7%) with a complete closure rate of the anterior layer of the abdominal wall of 97% [23]. Zolin et al. reported a 92% success rate in closing the anterior layer, with a composite hernia recurrence rate of 26% in a case series of 1,203 patients, 57% of whom had recurrences and a median hernia width of 15 cm [24]. The effectiveness of this technique in terms of recurrence was also reported by Winder et al. In their study, although with a smaller group of patients, the authors reported a 2.7% recurrence rate [25]. Heniford et al. confirmed these results in their study of 1,023 patients in whom PCS with TAR was performed in case of dissection difficulties with the pure preperitoneal

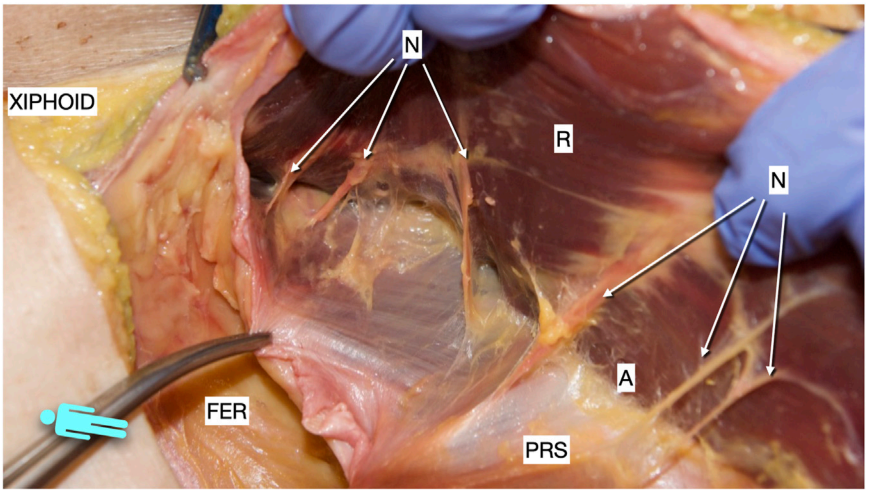

FIGURE 10 | Picture taken of a defrosted cadaver in which an incomplete Rives was dissected. It shows the medial arise of the medial merge of the nerves in the epigastric area. R, rectus muscle; PRS, posterior rectus sheath; FER, fatty epigastric rhomboid; A, ambivium; N, terminal branches of intercostal nerves.

technique, reporting a 5% recurrence rate [10]. Finally, Sagnelli et al, in their recent study, reported excellent results regarding the effectiveness of the technique. In their case series of 117 patients with complex IH, PCS with TAR was performed, and the abdominal wall was reconstructed with a double prosthesis, following the Madrid APPROACH, with a reported recurrence rate of less than 1% [13]. In this current case series, where the Madrid PCS was performed, we report a recurrence rate of 1.9%, lower than most studies in the literature, confirming that this technique is a valid alternative to the original one.

One of the key points of the Madrid PCS is the reconstruction using very large meshes, applying Stoppa´s concept of "giant reinforcement of the visceral sac" to the midline IH [6]. The space for this mesh is obtained by a wide dissection over the parietal peritoneum and under the overlying abdominal wall muscles: from Cooper's ligament to the central tendon, and from the tip of the twelfth rib and the psoas muscles to the contralateral ones. Anatomical findings have shown that this vast retromuscular and preperitoneal space includes the PRS, the preperitoneal trident, the parietal peritoneum, the fascia transversalis, and the fascia diaphragmatica [**Figure 8**]. This thin layer is referred to as"the posterior layer" in PCS techniques. Its use provides sufficient extension and overlap to effectively repair large defects in the midline and the combination of midline and lateral ones [26]. The difference with complete preperitoneal dissection [10,27] is that with the Madrid PCS, the medial and lateral release facilitates the midline closure of large defects.

Although the Madrid PCS was initially considered a modification of the TAR [11, 12, 14, 28], the significant anatomical differences probably suggest that it should be categorised as a PRS release rather than a TAR. These differences are: first, the preservation of the PRS insertion, and second, the lateral release of the PRS without cutting the TA muscle [**Figure 9**]. The first aspect involves the cranial preservation of the PRS at its physiological attachment to the chondrocostal cartilage. Anatomical dissections in the cadaver laboratory and experience in performing PCS have shown us that there is a close anatomical and, therefore, functional relationship between the PRS, the diaphragm, and the TA muscle. We have observed that the fibres of the diaphragm invariably insert at the PRS. Therefore, maintaining the integrity of the PRS avoids injury to these diaphragmatic fibres. Consequently, it seems convenient to change to a preperitoneal plane in the subxiphoid area. When we started learning the TAR technique, we became aware that the terminal branches of the T7, T8, and T9 intercostal nerves arise more medially than previously reported and they are difficult to preserve unless the TAR is performed very medially [**Figure 10**]. It is not so uncommon to see muscle atrophy of the rectus muscle in CT controls and patients complaining of a bulge. We then decided to perform the lateral release of the PRS in the upper third, following the myofascial limit of the TA muscle. Since this medial release is more difficult to perform than a TAR, we have standardised the technique with our recommendation to follow the pathways of the preperitoneal plane before starting the lateral release. Therefore, before any release is made, we recommend entering the preperitoneal plane starting at the Bogros space and pre-transversalis fascia in the subxiphoid area. As explained previously [21], the preperitoneal fat distribution allows entering the plane under the TA muscle without any lateral release at the PRS. Finally, the Madrid PCS is a technique halfway between Novitsky´s TAR and Heniford´s preperitoneal repair [7,9,10]. Furthermore, preserving the TA muscle cranially may contribute to the stabilisation and mobilisation of the trunk.

Another point of discussion is the difference in midline approximation obtained comparing the Madrid PCS and TAR. We certainly think that, from an anatomical point of view, we are also performing a release at the insertion of the TA muscle, and the difference must only be in the cranial preservation of the PRS. Anatomical studies in the cadaver laboratory may reveal if there is a substantial difference, although we agree that these cadaver studies may have significant limitations [29].

Despite good results in terms of recurrence rate, any complex abdominal wall repair is not free from complications. Novitsky et al, in their study, reported an SSE rate of 18% and an SSI rate of 9% with a mean length of hospital stay of 6 days [23]. Heniford et al. reported a 27% SSE rate and a 15% SSI rate with a mean length of hospital stay of 5 days [10]. However, in a subsequent study, the same authors demonstrated how experience can significantly improve the complication rate (from 26% to 13%) and the recurrence rate (from 7% to 2%) [27]. Sagnelli et al. also showed complications that were in line with those reported in the Literature. They reported a seroma rate of 26%, a hematoma rate of 17%, and only a 3.4% SSI rate [13]. Slightly better results were obtained by Zolin et al, who reported only 8% of SSOPI in patients with more than 1 year of follow-up [24]. Finally, a recent meta-analysis, including 5 studies from 2016 to 2017, reported similar results, with an average SSO rate of 15% and an SSI rate of 7% [30].

In our case series, 38% of patients experienced a complication, either systemic or related to the surgical site. The reported rates of seroma and SSI were 17% and 16%, respectively. Of these, only one patient, who also underwent simultaneous intestinal transit reconstruction, required reoperation to completely remove the infected mesh. With regard to late infections, 7 (3%) patients were readmitted for treatment. Of these, 5 patients had a mesh infection, and in all cases, the prosthesis was removed. Compared to other studies, our results regarding postoperative complications were higher, which could be influenced by the patient´s non-ideal preoperative conditions and the careful collection of prospective data. Approximately 85% of our patients had at least one comorbidity, and 67% had a CeDAR score of developing a surgical site complication between 30% and 60%. Furthermore, 53% and 24% of the patients were classified as grade 2 and 3 according to the Ventral Hernia Staging System (VHSS) classification [31].

There are several notable limitations. There is no comparison group. This design choice limits the ability to assess the relative effectiveness and safety of the Madrid PCS compared to alternative surgical approaches. However, we do consider this approach to be the most anatomically respectful. The population treated at three specialised centres also limits its applicability to other centres not dedicated to the abdominal wall. The study may be subject to selection bias since patients were recruited from specialised centres, and those with more complex cases or comorbidities may be overrepresented. This could impact the external validity of the findings. On the other hand, the selection criteria for enrolling patients avoid selection bias and the application of the same protocol prevents the bias of misclassification. Finally, we recognise an inherent publication bias due to the tendency to publish positive results, potentially leading to an overestimation of the effectiveness of the Madrid PCS. technique. Nonetheless, this study offers a large sample reporting favourable long-term outcomes demonstrating the durability and sustained effectiveness of the Madrid PCS in addressing midline incisional hernias. Additionally, the main aim of this study was to provide a comprehensive description of the surgical technique based on anatomical findings. This knowledge is considered crucial for surgeons, suggesting that a thorough anatomical approach contributes to the success of this technique.

CONCLUSION

The Madrid PCS stands out as a technique that facilitates the reconstruction of large IHs with remarkable efficacy in preventing recurrence. This approach introduces a technical variation rooted in the anatomical study of the abdominal wall and the arrangement of its preperitoneal fat. These modifications not only improve the intuitive execution of the technique but also foster a more respectful approach to the musculofascial and nervous components of the anterior abdominal wall. Furthermore, the Madrid PCS allows for the placement of large prostheses in the retromuscular-preperitoneal space, aligning with the fundamental principle of the giant prosthetic reinforcement of the visceral sac. This adherence contributes to a low incidence of long-term recurrences, contributing to the favourable outcomes associated with the technique.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because the authors confirm that the data supporting the findings of this study are available within the article (and/or) its supplementary materials. Requests to access the datasets should be directed to cellodeluca@gmail.com.

ETHICS STATEMENT

The study was approved by the Research Ethics Committee of Francisco de Vitoria University (39/2019) and the Institutional Review Board (37/2022). The patients provided written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

All authors participated in the design and interpretation of the study. MD, MM, SM, and JM analyzed the datas. MD and MG-U wrote the manuscript, AR, JL, and LB reviewed of the manuscript. All authors contributed to the article and approved the submitted version.

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CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

PUBLISHER'S NOTE

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