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Mesh-Based Hernia Repair: Advances, Complications, and Future Perspectives

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ABSTRACT

Background and Objective: More than six decades have passed since the first open hernia repair, and the hernia meshes are still fundamental in abdominal wall surgery. The open, laparoscopic, and robotic approaches all have unique advantages. The objective of this review is to discuss the current hernia repair procedures, surgical mesh selection, associated complications, and future trends in hernia mesh development.

Methods: This review assesses surgical approaches and hernia mesh materials, focusing on mesh design and selection, tissue integration, foreign body reaction, and chronic functionality, which are directly impacted by material composition, porosity, textile architecture, and mechanics. Biological, absorbable, synthetic, and innovative mesh technologies were also considered.

Results: Although surgical meshes significantly reduce recurrence rates as compared to traditional suture repair, important clinical complications, including infection, adhesion, seroma formation, chronic pain, and mesh migration, still exist. A mesh design and selection are key factors affecting the surgical outcome. Synthetic meshes are still popular due to their durability, ease of handling, and cost-effectiveness, while biological and absorbable options are suitable in contaminated environments and in high-risk patients. While these meshes have progressed, none have yet shown optimal performance across all clinical indications.

Conclusion: Research in the future is directed towards development of biocompatible mesh, reduction of complications and enhancement of patient quality of life. Innovative approaches, such as nanofiber scaffolds, bioactive coatings and hybrid materials, have the potential to contribute to the realization of the “ideal” hernia mesh. Until then, a tailored surgical routine and ongoing advancements in mesh technology remain essential for achieving optimal hernial repair.

Keywords: Hernia, mesh, hernioplasty, future Perspectives.

Introduction

A hernia is a protrusion of an internal organ or tissue through a weakness in the surrounding muscle or connective tissue. In abdominal hernias, this protrusion typically involves the peritoneum, the serous membrane lining the abdominal cavity and completely or partially enclosing most abdominal organs, forming what is known as the hernial sac [1]. Hernias are classified into inguinal (most common, mainly in males) [2]. femoral (more common in females)[3]. incisional (at previous surgical sites)[4]. umbilical (around the umbilicus) [5]. epigastric (between the xiphoid and umbilicus)[6]. Ventral Hernia Protrusion of the abdominal contents through the defect in the ventral abdominal wall [7]. Diaphragmatic hernias are slightly different from other types of hernias, as they are not externally visible; they occur when a defect or widening in the diaphragm allows the peritoneum or abdominal organs, such as part of the stomach, to herniate from the abdominal cavity into the thoracic cavity. Hernias that are not visible from the outside are sometimes called "internal hernias''[8]. Typically, internal organs are pushed through the hole in the abdominal wall, causing discomfort or pain in the area. Hernias frequently recur in patients who undergo surgical treatment. This is likely due to a decrease in suture tension over time and disturbances in collagen metabolism [9]. Ultrasonography was found to have a specificity of 100% for the diagnosis of hernias, [10]. Hernias can be diagnosed by various methods, such as physical examination by inspection and palpation, but clinical diagnosis is sometimes difficult, especially in the situation of obese animals or presence of scarring or adhesion in the abdominal wall. In these situations, abdominal imaging may lead to another clue in the right direction for diagnosis and to prove any suspected hernia [11]. Ultrasonography (US), computed tomography (CT), and traditional radiography or CT, which are cross-sectional modern imaging, helping in differentiate between different palpable abdominal wall masses and characterize hernial contents such as fatty tissue, the colon, other organs, or fluid [12].

Hernia repair

Hernia repair surgery is a procedure performed to correct a hernia, a condition in which an organ or tissue protrudes through a weak area in the surrounding muscle or connective tissue. The operation is typically undertaken to return the protruding structures to their normal anatomical position and to reinforce the weakened area using sutures and/or prosthetic mesh, thereby restoring the integrity of the abdominal wall. This can be performed via open surgery or laparoscopic surgery, with the latter being a minimally invasive approach. The open Surgery involves a larger incision to access and repair the hernia. It involve two method the traditional non-mesh herniorrhaphy and Mesh hernioplasty [13]. Non-mesh herniorrhaphy includes: shouldice Repair which involves creating flaps from tissue layers and overlapping them to reinforce the weakened area, often using sutures (fig.1) [14].

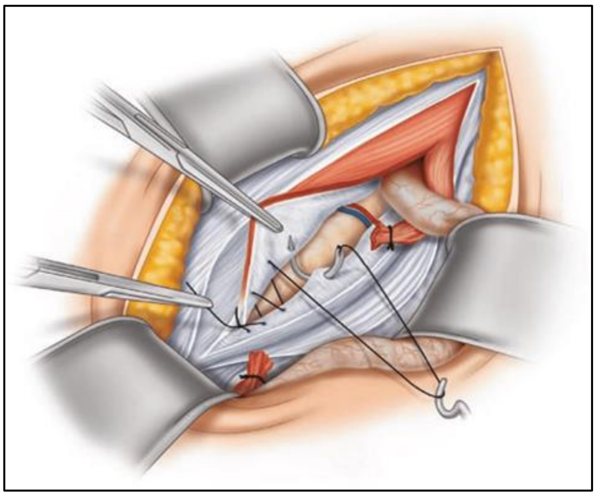

Figure.1: Shouldice procedure for hernia Repair [15].

Bassini Repair: It is based on the anatomical reconstruction of the inguinal canal by suturing the common tendon to the inguinal ligament, with the aim of restoring normal anatomical structures without the use of mesh. (fig.2) [13].

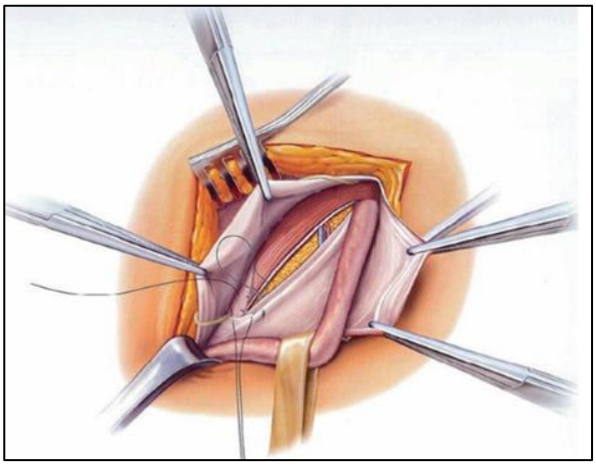

Figure.2: Bassini procedure for hernia Repair [15]

A hernia mesh repair is a type of hernia repair procedure. A mesh plug is inserted into the hernia repair opening and then secured with a mesh patch. This technique can strengthen weakened areas and prevent recurrence. A tapered mesh plug is inserted into the hernia repair opening, and a larger mesh patch is then placed over the plug and surrounding area to provide additional support and reinforcement. (Fig.3). [16].

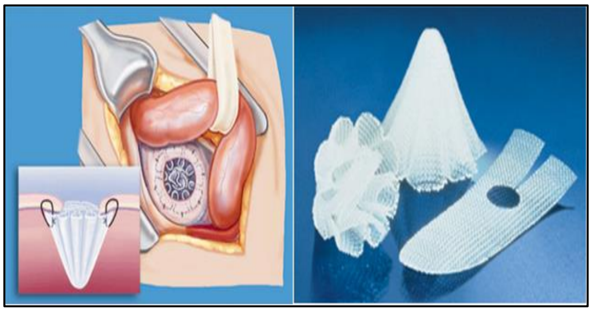

Figure.3: mesh (plug) using for inguinal hernia repair [17].

Stoppa Procedure: procedure consists of placing a large mesh in preperitoneal position enveloping the sub-umbilical peritoneal sac and covering all the hernia orifices(Fig.4) [18].

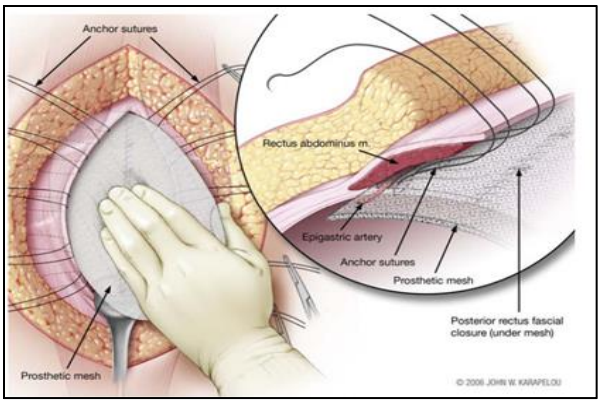

Figure.4: Stoppa Procedure for ventral hernia repair [19].

Laparoscopic hernia repair: A minimally invasive procedure that uses several tiny incisions and special tools, which may include a laparoscope (a telescope-like instrument with a camera) to fix a hernia. Total extraperitoneal (TEP) hernia repair is a safe and effective procedure for minimally invasive hernia repair, which is performed without surgical entrance to the peritoneum. This method employs a mesh to maintain the anatomy and physiology of the abdomen, which resulting in low trauma and low complications in the postoperative course. [20,21]. Transabdominal Preperitoneal Repair (TAPP) : is a laparoscopic procedure most commonly used for inguinal and ventral hernias involving creating and closing a peritoneal flap to access the preperitoneal space to place mesh. The technique starts with opening the abdominal cavity and some blunt or sharp dissection to create the found-peritoneal flap exposing the preperitoneal space. Following reduction of the hernia sac and placement of the mesh, the peritoneal flap is closed over the mesh to complete the repair [22].

Robotic surgery for repairing of hernia: is a minimally invasive technique where a surgeon controls robotic arms equipped with instruments and a camera from a console to perform the surgery. This approach offers enhanced 3D visualization, precise movements, and greater dexterity for the surgeon, resulting in smaller incisions, less pain, reduced tissue damage, and potentially faster recovery times compared to traditional open surgery. The technology is used for various types of hernias, including complex cases that may be challenging to treat with standard methods [23].

Mesh in Hernia Repair

Surgical meshes have been used since 1891, especially for hernia repair. a hernia surgical is a medical device, usually a screen made of woven or knitted, which purposely to reinforce and strengthen the weakened tissue surrounding the hernia when it is surgically repaired. It serves as a framework within which tissue can grow into and around the mesh, providing stability and significantly reducing the potential for recurrence. According to the type of hernia, risk factors specific to the patient as well as surgeon taste, the sort of mesh is chosen. There are many different kinds of meshes, however, and vigorous debate exists regarding optimal performance and surgical outcomes. [24].

Classification of Mesh:

By Material Composition:

Laparoscopic hernia repair: here, several small cuts are made in the abdomen, and a laparoscope (a telescope-type instrument with a video camera), along with narrow instruments to patch the hernia, are used. Total extraperitoneal hernia (TEPH) repair or total extraperitoneal approach hernia repair or simply extraperitoneal hernia repair is a safe and practical method of minimally invasive hernia repair which avoids the need for a surgical approach in the abdomen. This method uses a network to maintain the anatomy and physiology of the abdominal wall with the least possible damage and postoperative includes less complications [25]. Polypropylene mesh is a non-absorbable, high-strength material that has good mechanical stability and strength, is resistant to biodegradation, is electrostatically neutral, highly hydrophobic, and non-polar. [26]. Although polypropylene mesh offered many benefits, problems such as stiffness, shrinkage, and localized cracking were seen after its use. While such drawbacks are acknowledged, polypropylene continues to be the most frequently used absorbable mesh material due to the ease of fiber production, durable strength at 10 and 20 years, low cost, and ease of handling [27]. Polyester is composed of polyethylene-terephthalate (PET) were firstly used as surgical meshes in 1960 for repairing of inguinal and abdominal hernias [28]. It is a soft and pliable material suitable for web construction. It is slightly polar, more hydrophilic and hygroscopic than homopolymeric hydrocarbon polymers. Polyester fibers are very strong, tough, and resistant to most chemicals. [26]. Its textile structure may be mono- or multi-flament. Meshes now have different configurations for different types of hernia repairs, such as incisional, inguinal and hiatal hernia repair [27]. Expanded polytetrafluoroethylene (ePTFE) is a microporous form of the polymer polytetrafluoroethylene (PTFE), a synthetic polymer composed of carbon and fluorine with strong carbon-fluorine bonds. These strong bonds give polytetrafluoroethylene (PTFE) its exceptional chemical inertness and non-stick properties, while the expanded structure imparts its flexibility and porous network of polytetrafluoroethylene (PTFE) fibers and nodes. Due to its chemical stability, Expanded polytetrafluoroethylene (ePTFE) is inherently inert and resists degradation in the body [29]. Its pore size is smaller than that of polypropylene, with larger pores on one side and smaller pores on the other. This can inhibit intestinal adhesions and prevent tissue ingrowth into the abdominal wall, which can ultimately lead to encapsulation and worsen hernia repair effectiveness. Intraperitoneal Expanded polytetrafluoroethylene (ePTFE) offers advantages such as minimal inflammatory response and low scar density, but good fixation is also crucial, as Expanded polytetrafluoroethylene (ePTFE) is prone to fracture. [27]. Another important characteristic of this material is its porosity. Due to the mesh's microporous structure, macrophages are unable to penetrate the material during infection. Therefore, mesh removal is essential, especially when used in open ventral hernia surgery. [30]. Partially absorbable mesh: is a hybrid implant, blending permanent, non-absorbable materials like polypropylene with absorbable materials such as polyglactin or poliglycaprone, designed to offer the immediate strength of permanent meshes while gradually reducing the long-term foreign body presence [31]. This composition aims to provide sufficient structural support for hernia repair and tissue healing in the crucial early postoperative period, after which the absorbable portion dissipates, leaving a lighter, less foreign scaffold and potentially improving long-term patient outcomes like reduced pain and foreign body sensation [32]. Absorbable mesh: Polyglactin (multifilament, synthetic mesh that is completely absorbed by the body) , poliglecaprone (monofilament, synthetic mesh that is also absorbable and used for soft tissue repair)[33], are used in contaminated surgical fields to avoid chronic infection and the need for mesh removal but provide weaker, temporary reinforcement, with the mesh completely degrading within 90-180 days [34]. This temporary support allows the body's tissue to heal without the long-term complications associated with permanent synthetic meshes in infected environments [35].

Biological meshes are derived from human, bovine, and porcine tissues and decellularized to retain the collagen matrix. This structure serves as a regenerative scaffold, supporting collagen remodeling and neo collagenesis. The properties of each material vary, depending on the tissue source and the specific methods used to remove cells and sterilize the graft. This processing can cause subtle biochemical changes in the collagen structure, impacting graft biocompatibility, foreign body reactions, and immunogenicity. [33]. These meshes can be classified according source and absorbency into: allografts are the transplant of tissue, cells, or an organ from one individual to another, where the donor and recipient are of the same species. These grafts can come from a deceased donor (cadaver) or a living donor and are used in various medical procedures [36, 37]. A xenograft is the transfer of cells, tissues, or an organ from a donor of one species to a recipient of a different species. This process, also called heterograft, is a crucial tool in medical research and clinical applications (38, 39). Autologous tissue grafts, or autografts, involve transferring tissue from one part of a patient's body to another, providing the body's own material for healing and reconstruction. This "gold standard" method offers the highest biocompatibility and avoids immune rejection, but requires a second surgical site to harvest the tissue, which adds to recovery time and potential discomfort [40].(Table.1).

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Table 1: Graft categories and their potential outcomes.

Types of grafts	The donor	The Recipient	Estimated adverse consequences
Allograft	The donor and recipient must be of the same species	The donor and recipient must be of the same species	The rejection may be anticipated.
Xenograft	Animal	Human	The rejection may be highly anticipated
Autograft	The donor is the self	the recipient is self	No anticipated rejection

By Structure: the meshes can be classified according to Porosity, Woven Basics and Weighting of mesh. Porosity, which is the key factor influencing tissue reactivity to the mesh is pore size, which is defined as the ratio of the volume of voids in the mesh to the overall volume of the mesh [27]. Cell proliferation and bacterial growth depend strongly on porosity [41]. Mesh is divided into: Large pore mesh refers to a mesh with a larger pore size, generally with a pore size of >75μm, which can allow a large amount of tissue to grow in, immune cells to penetrate, reduce the risk of infection, and integrate with surrounding body tissues [42]. These structures, often made from materials like polypropylene, are widely used in medical applications such as hernia repair to provide structural support and promote healing. The large pore size encourages parietal tissue integration, which helps to anchor the mesh and strengthen the repaired tissue [9]. Microporous meshes have pore sizes typically less than 75-100 micrometers (μm), which impedes human cellular penetration and tissue ingrowth, leading to a higher risk of infection due to the inability of immune cells to access bacteria. Common examples of microporous materials used in meshes include ePTFE (expanded polytetrafluoroethylene) [43] (Table.2). granulomas normally form around individual surgical mesh fibers as a foreign body reaction, involving macrophages, lymphocytes, and fibroblasts, which eventually lead to the formation of a collagen capsule. This reaction aims to encapsulate the foreign material and is influence d by the mesh's pore size, with larger pores promoting better tissue ingrowth and flexibility by avoiding the formation of granuloma bridging [44] (Fig.5).

Table 2: Mesh porosity categories used for hernia repair

Type	Specifications	Example
Macroporous mesh	pore size >75 μm	Polypropylene and prolene
Microporous mesh	pore sizes <75-100 μm	Expanded polytetrafluoroethylene (ePTFE)

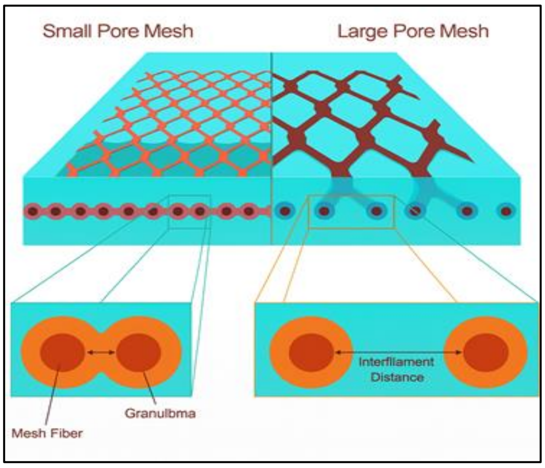

Figure.5: Granulomas confluence when pores are tiny, resulting in the loss of any functional pores. While in large-pore meshes, Granulomas round the mesh fibers but do not fill the whole pore [43].

Fabric Basics: Mesh textile structures can be woven, nonwoven, or knitted from monofilament or multifilament fibers (Figure 6). Woven meshes used for hernia repair are surgical materials made from interwoven threads that cross to form a stable structure that supports delicate tissue. These meshes allow tissue in-growth into their pores, thereby enhancing the repair, increasing closure strength, and reducing the risk of hernia recurrence. While woven meshes are effective, they can cause side effects such as infection and adhesions. Nonwoven mesh structures are composed of interlocking or bonded fibers. Due to their microporous structure, they promote connective tissue ingrowth and reduce adhesions more than woven meshes. [41]. Knitted mesh has a special knitting structure and is often used as a warp knitted fabric. Knitted mesh has structural stability, flexibility, high porosity, excellent tear resistance and a diverse structure, making it more elastic and anisotropic than non-woven mesh. [45]. Its larger pore size creates conditions for macrophage infiltration, promotes tissue growth, and reduces the risk of postoperative infection. In addition, warp knitted fabrics have good mechanical properties and can increase the strength of the defective abdominal wall. [46].

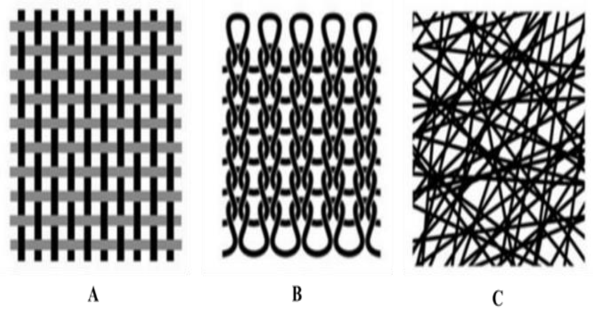

Figure.6: Diagrammatic graphic of textile structure of mesh, woven (A) warp knitted (B) and non-woven (C) [27].

Weighting of mesh: another crucial element in mesh design is weight. Mesh weight is mostly determined by pore size, however it is also somewhat influenced by polymer weight, so the mesh can be divided into lightweight (generally <50 g/m²) or heavyweight (generally >90 g/m²), with heavyweight meshes using thicker polymers and having smaller pores, while lightweight meshes utilize thinner filaments and larger pores [44], which can lead to less inflammatory response, better tissue incorporation, and increased patient comfort. The choice between lightweight and heavyweight mesh depends on the specific type of hernia and the surgical approach, with ongoing debate in the surgical community regarding their long-term outcomes and ideal characteristics [47]. (Table.3).

Table 3: Mesh weight categories

Type	Weight	Highlights characteristics
Light-weigh	35–50 g/m²	Thinner filaments, large pores, reduced foreign body reaction and stiffness
Heavy-weigh	> 90 g/m²	Thick filaments, small pores; maximal strength but higher inflammatory response

Mesh locations:

Ventral hernia repair remains one of the most frequently performed abdominal wall procedures, yet the ideal anatomic placement of mesh continues to be debated despite decades of research [47]. Successful outcomes depend not only on the size and type of mesh selected but also on the surgical plane in which it is implanted [48]. Currently, five major anatomic planes of mesh placement are widely recognized in ventral hernia repair. On-lay, When the mesh is positioned between the subcutaneous tissue and the anterior rectus sheath, it is said to be implanted on-lay [49]. Onlay placement. During an onlay placement procedure, a mesh is placed between the tissue edges of the abdominal wall where the defect is located. The mesh adheres to the edges of the defect, forming a bridge and closing the defect hole. [49]. Sub-lay, the mesh is implanted below the repaired muscle, which is known as sub- Implantation. The implantation site can be between the peritoneum and the rectus abdominis muscle or between the rectus sheath and muscle.)[50]. Underlay: The mesh is inserted in front of the peritoneum, behind the rectus sheath. This is also called preperitoneal placement. If the mesh is inserted into the abdominal cavity and placed deep within the anterior peritoneal wall, it is called intraperitoneal placement (IPOM). This often requires bridging, especially during laparoscopic surgery. [51] (Fig.7).

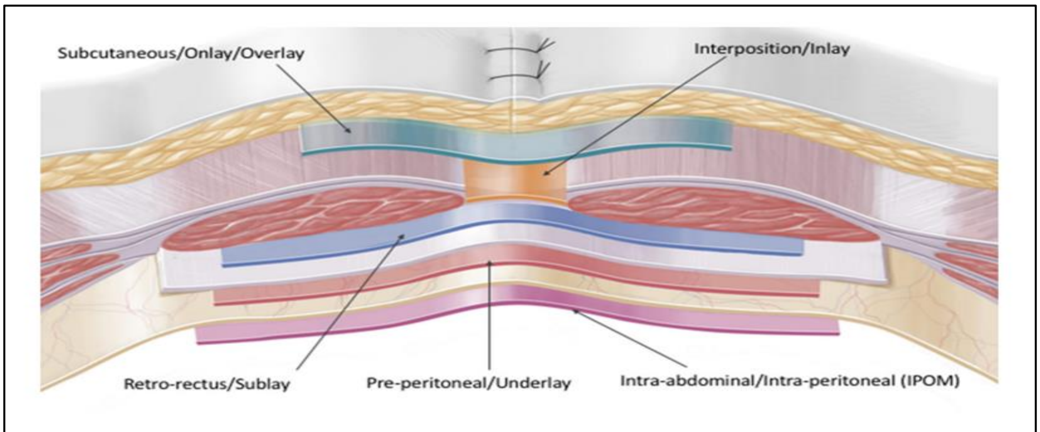

Figure.7: Illustration showing the mesh placement locations during the ventral hernia repair [51].

Mesh Selection Considerations

Mesh is selected based on hernia type and location such as inguinal, ventral, incisional hernia [52]. surgical approach (open or laparoscopic). Key mesh properties to consider are its weight (lightweight is preferred for comfort and lower infection risk), pore size (large-pore is better for tissue ingrowth and flexibility), and material (monofilament, often polypropylene, is common) [53]. Wound condition, such as the presence of infection [54], also influences selection, with absorbable meshes used in infected cases. Adequate sizing to prevent shrinkage and a suitable placement technique are crucial for reducing recurrence and chronic pain [55].

Complications Related to Mesh hernioplasty:

The most common hernia mesh complications are **adhesion;** post-operative adhesions are pathological connections that develop between surfaces inside bodily cavities. They can be as thin as a connective tissue layer or as thick as fibrous bridges that are home to nerve and blood arteries. Many causes of postsurgical adhesion including thermal damage, trauma, infection, ischemia, and implant foreign materials like mesh and suture materials [56]. **Seroma;** It refers to the abnormal accumulation of serous fluid within the dead space, which contains lymph and plasma. Although the cause is unclear, it is currently believed to be related to the interruption of lymphatic and vascular drainage caused by extensive tissue dissection during surgery, as well as inflammatory exudate that may accumulate in the dead space after surgery. [57]. **Wound infection**; These included symptoms of welling, redness, pain which are consider as the characteristic feature of inflammatory reaction. Fever, scorching discomfort, and soreness one of the worst issues that may develop right away following surgical repairing of hernia [58]. The infections my not impotent when it is superficial. And my treated with antimicrobial agent and subsided during few days post treatment. Occasionally outcome in formation of deep abscess and deal with it as emergency case. Which need a second operation [59]. **Chronic pain**; chronic discomfort is outcome of using meshes and it's very concerning to the structure and material qualities which play a vital role in foreign body reactions [60]. **Mesh migration**; a rare but serious late complication after hernia repair, where the prosthetic mesh shifts from its original position and erodes into surrounding organs like the bladder or intestines. It can be caused by mechanical issues like inadequate fixation or by a foreign body reaction leading to tissue erosion and displacement [61]. **Erosion into adjacent organs;** a rare but serious complication, potentially causing pain, infection, fistulas, or organ obstruction, and is more common after pelvic floor or hernia repair surgeries. Common sites for erosion include the bladder, rectum, and small intestine [62]. **Recurrent hernia;** occurring at the same or a neighboring site after a previous hernia repair surgery is a well-defined medical condition. This recurrence can appear as a bulge or cause pain and is a known complication of hernia surgery. Recurrent hernias can happen for several reasons, including improper healing of the original surgery site, inadequate repair techniques, or the natural weakening of the abdominal wall over time [63, 64]).

Future Directions

Hernia repair mostly relies on the use of surgical mesh for therapy, which, while not ideal, has a lower recurrence rate. As a result, extensive research is being conducted to develop the next generation of surgical mesh, with an emphasis on addressing some mesh application concerns, focusing on biocompatibility, adhesion, and infection control. Nano fibrous barrier, hydrogel in the biological field, mats and surface coating with appropriate polymers and nanoparticles have shown very encouraging results. Mesh performance despite extensive research in this field and advances at lowering the recurrence rate, current meshes continue to be problematic. Suffer from post-infection, intestinal blockage, and organ adhesion treatment the most sought-after topic in hernia mesh research is still the development of an optimum hernia mesh [25].

Conclusion

Mesh-based hernia repair remains the gold standard for most hernia types, offering lower recurrence rates and superior durability compared to primary suture repair. However, mesh-related complications such as infection, adhesion, and chronic pain continue to pose significant clinical challenges, highlighting the need for careful patient selection and precise surgical technique. Although synthetic, absorbable, and biological meshes have each advanced the field, no single material has yet achieved the ideal balance of strength, biocompatibility, and safety. Ongoing innovations such as nanofibrous scaffolds, hybrid polymers, and bioactive coatings hold promise for the development of next-generation meshes that may further improve outcomes and patient quality of life.

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This review has been fulfilled by the Synergistic contribution of authors.

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إصلاح الفتق باستخدام الشبكة: التطورات والمضاعفات والرؤى المستقبلية

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الملخص

المقدمة والهدف: مرّت أكثر من ستة عقود على إجراء أول عملية جراحية مفتوحة لإصلاح الفتق، ولا تزال شبكات الفتق تشكل عنصراً أساسياً في جراحات جدار البطن؛ إذ تتميز كل من التقنيات المفتوحة، وجراحة المناظير، والجراحة الروبوتية بمزايا فريدة. وتهدف هذه المراجعة إلى مناقشة الإجراءات الحالية لإصلاح الفتق، ومعايير اختيار الشبكات الجراحية، والمضاعفات المصاحبة، والاتجاهات المستقبلية في مجال تطوير شبكات الفتق.

طرائق العمل: تُقيّم هذه المراجعة الأساليب الجراحية ومواد شبكات الفتق، مع التركيز على تصميم الشبكة واختيارها، والاندماج النسيجي، ورد فعل الجسم تجاه الأجسام الغريبة، والأداء الوظيفي على المدى الطويل؛ وهي جوانب تتأثر مباشرةً بتركيبة المادة، والمسامية، وبنية النسيج، والخصائص الميكانيكية. كما تناولت المراجعة تقنيات الشبكات البيولوجية، والقابلة للامتصاص، والصناعية، والمبتكرة.

النتائج: على الرغم من أن استخدام الشبكات الجراحية يقلل بشكل ملحوظ من معدلات عودة الفتق بشكل مقارنةً بالغرزالجراحية التقليدية، إلا أن المضاعفات السريرية الهامة، بما في ذلك العدوى والالتصاقات وتكوّن الورم المصلي والألم المزمن وانزياح الشبكة، لا تزال قائمة. ويُعد تصميم الشبكة واختيارها من العوامل الرئيسية المؤثرة على نتائج الجراحة. ولا تزال الشبكات الاصطناعية شائعة الاستخدام نظرًا لمتانتها وسهولة استخدامها وفعاليتها من حيث التكلفة، بينما تُعد الخيارات البيولوجية والقابلة للامتصاص مناسبة في البيئات الملوثة ولدى المرضى المعرضين لمخاطر عالية. ومع أن هذه الشبكات قد شهدت تطورًا، إلا أنه لم يُظهر أي منها حتى الآن الأداء الأمثل في جميع الحالات السريرية.

الاستنتاج: تتجه الأبحاث المستقبلية نحو تطوير شبكات متوافقة حيوياً، والحد من المضاعفات، وتحسين جودة حياة المرضى, إذ تمتلك الأساليب المبتكرة مثل السقالات المصنوعة من الألياف النانوية، والطلاءات النشطة حيوياً، والمواد الهجينة التي لها القدرة على المساهمة في التوصل إلى شبكة "مثالية" لعلاج الفتق. وحتى يتحقق ذلك، تظل الإجراءات الجراحية المصممة خصيصاً لكل حالة والتطورات المستمرة في تكنولوجيا الشبكات أمراً جوهرياً لتحقيق أفضل النتائج في إصلاح الفتق.

الكلمات المفتاحية: الفتق، الشبكة، جراحة إصلاح الفتق، الآفاق المستقبلية.