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INNOVATIVE TECHNIQUES IN SPERMATIC CORD-SPARING HERNIOPLASTY (LITERATURE REVIEW)

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Abstract

Inguinal hernia repair, a globally common procedure, has shifted its focus from minimizing recurrence to mitigating Chronic Postoperative Inguinal Pain (CPIP) and preserving the intricate neurovascular structures of the spermatic cord (SC). CPIP and reproductive system compromise, often stemming from surgical trauma, nerve entrapment, or mesh-induced inflammation, necessitate innovative strategies that prioritize SC integrity. This comprehensive review evaluates advancements across surgical approach, material science, and regenerative medicine designed to improve patient quality of life.

Analysis confirms that minimally invasive laparoscopic approaches (TAPP and TEP) consistently yield lower chronic pain rates than open mesh repair, primarily by reducing tissue trauma and dissection of the SC. Material innovations focus on lightweight and three-dimensional meshes, along with the adoption of atraumatic fixation techniques, such as bio-adhesives or non-fixation, to prevent nerve and cord compression. The most precise cord-sparing innovation is microsurgically assisted hernia repair, which uses high magnification for meticulous anatomical preservation, demonstrating superior outcomes regarding pain and vas deferens injury.

Emerging regenerative techniques include using biocompatible barrier membranes to shield the SC from the inflammatory effects of synthetic mesh, as well as developing dynamic scaffolds designed to promote de novo formation of muscle and nerve tissue, moving away from simple fibrotic reinforcement. Although conventional synthetic mesh remains the standard due to high recurrence rates associated with current biological materials, future perspectives necessitate robust clinical validation of these precision and regenerative methodologies to firmly establish truly cord-sparing hernioplasty standards.

Keywords: Inguinal hernia, spermatic cord, cord-sparing hernioplasty, minimally invasive surgery, mesh innovation, chronic postoperative inguinal pain, regenerative surgery, microsurgical repair, biological mesh, platelet-rich plasma

SPERMATIK KANALNI SAQLAB QOLISHGA YO‘NALGAN INNOVATSION GERNIYOPLASTIKA USULLARI (ADABIYOTLAR TAHLILI)

Annotatsiya

Ingvinal churrani davolash dunyo bo‘yicha keng tarqalgan jarrohlik amaliyotidir. So‘nggi yillarda ushbu operatsiyalar diqqat markazini qaytalanishlarning oldini olishdan ko‘ra, operatsiyadan keyingi surunkali ingvinal og‘riqni (CPIP) kamaytirish va spermatik kanal (SK) ning murakkab neyrovaskulyar tuzilmalarini saqlab qolishga qaratmoqda. CPIP va reproduktiv tizim faoliyatining buzilishi ko‘pincha jarrohlik travmasi, nervning qisilib qolishi yoki to‘r materialining yallig‘lanish reaktsiyasi tufayli yuzaga keladi. Shu sababli SK yaxlitligini ustuvor saqlovchi innovatsion yondashuvlar zarur.

Tahlillar shuni ko‘rsatadiki, minimal invaziv laparoskopik usullar (TAPP va TEP) ochiq to‘rli gerniyoplastikaga nisbatan to‘qimalarga kamroq travma yetkazgani uchun surunkali og‘riq holatlarining pastroq darajada bo‘lishiga olib keladi. Materialshunoslikdagi yangiliklar yengil, uch o‘lchamli to‘rlar va bio-yopishtiruvchi yoki umuman fiksatsiyasiz texnikalardan foydalanishga asoslanadi. Bu yondashuvlar nerv va kanalning siqilishining oldini oladi. Eng aniq SK-ni saqlovchi yondashuv mikrojarrohlik yordamida bajariladigan gerniyoplastika bo‘lib, u anatomik

tuzilmalarning yuqori kattalashtirish ostida nozik aniqlik bilan saqlanishini ta’minlaydi va og‘riq hamda vas deferens shikastlanishining kamayishini ko‘rsatadi.

Regenerativ jarrohlikdagi yangi yo‘nalishlar sintetik to‘rning yallig‘lanish ta’siridan SKni himoya qiluvchi biokompatibil membranalardan foydalanish hamda mushak va nerv to‘qimalarining qayta hosil bo‘lishini rag‘batlantiruvchi dinamik skelet tuzilmalarini ishlab chiqishni o‘z ichiga oladi. Hozirgi kunda sintetik to‘r yuqori qaytalanish darajasi sababli standart bo‘lib qolmoqda, biroq kelajak istiqbollari ushbu aniqlik va regenerativ metodlarning klinik samaradorligini isbotlashni talab qiladi. Bu yondashuvlar haqiqiy “kanalni saqlovchi” gerniyoplastika standartlarini shakllantirish uchun asos bo‘ladi.

Kalit so‘zlar: ingvinal churrasi, spermatik kanal, kanalni saqlovchi gerniyoplastika, minimal invaziv jarrohlik, to‘r innovatsiyasi, surunkali operatsiyadan keyingi og‘riq, regenerativ jarrohlik, mikrojarrrohlik, biologik to‘r, trombotsitlarga boy plazma.

ИННОВАЦИОННЫЕ МЕТОДЫ ГЕРНИОПЛАСТИКИ С СОХРАНЕНИЕМ СПЕРМАТИЧЕСКОГО КАНАТИКА (ОБЗОР ЛИТЕРАТУРЫ)

Аннотация

Операции по поводу паховой грыжи — одни из самых распространённых хирургических вмешательств в мире. Современные подходы смещают акцент с предотвращения рецидивов на снижение частоты хронической послеоперационной паховой боли (CPIP) и сохранение сложных нейроваскулярных структур семенного канатика (СК). CPIP и нарушения репродуктивной функции зачастую возникают вследствие хирургической травмы, ущемления нервов или воспалительной реакции на имплантируемый сетчатый материал. Это определяет необходимость инновационных методик, направленных на максимальное сохранение целостности СК.

Анализ показывает, что минимально инвазивные лапароскопические методы (TAPP и TEP) обеспечивают более низкий уровень хронической боли по сравнению с открытой герниопластикой с сеткой, главным образом за счёт меньшей травматизации тканей и ограниченного рассечения СК. Технологические инновации направлены на применение лёгких трёхмерных сеток и атравматичных способов фиксации (биоадгезивы или отсутствие фиксации), что предотвращает компрессию нервов и структур канатика. Наиболее точным методом, сохраняющим СК, считается микроскопически ассистированная герниопластика, обеспечивающая высокоточное сохранение анатомических структур и минимизацию повреждения vas deferens и болевого синдрома.

К перспективным направлениям относятся регенеративные технологии — использование биосовместимых барьерных мембран для защиты СК от воспалительного воздействия сетки, а также разработка динамических матриксов, стимулирующих регенерацию мышечной и нервной ткани, уходя от грубого фиброзного рубцевания. Несмотря на то, что синтетические сетки пока остаются стандартом из-за высокой частоты рецидивов при биологических материалах, будущее герниопластики требует клинически подтверждённых прецизионных и регенеративных подходов для установления истинных стандартов операций с сохранением семенного канатика.

Ключевые слова: паховая грыжа, семенной канатик, герниопластика с сохранением канатика, минимально инвазивная хирургия, инновации сетчатых имплантов, хроническая

послеоперационная паховая боль, регенеративная хирургия, микрососудистая герниопластика, биологическая сетка, плазма, обогащённая тромбоцитами.

Introduction

Inguinal hernia (IH) repair is recognized as one of the most frequently performed surgical procedures globally, with approximately 20 million operations conducted annually (Messias et al., 2024; Abebe et al., 2022; Carreño-Sáenz et al., 2024; Tigora et al., 2025; Arrey et al., 2025). IH accounts for about 75% of all abdominal wall defects (Kamani et al., 2024; Messias et al., 2024). Historically, the foundational shift in the field moved from tension-based techniques to tension-free approaches, leading to a profound reduction in recurrence rates (Tigora et al., 2025; Romanowska et al., 2016). Mesh augmentation is considered the current standard for IH management, successfully lowering recurrence rates from around 6–7% seen with primary tension repairs to approximately 2–3% (Romano et al., 2025).

With the advent of prosthetic mesh leading to significantly reduced recurrence rates, the primary metric for surgical success has shifted to minimizing Chronic Postoperative Inguinal Pain (CPIP) and preserving genitofemoral function (Reinpold, 2017; Bracale et al., 2018). CPIP, defined as pain lasting more than three to six months post-surgery, is now the most common complication, with a clinically significant incidence ranging from 10% to 12% (Reinpold, 2017; Köckerling & Simons, 2018; Carreño-Sáenz et al., 2024). The genesis of CPIP is often attributed to neuropathological injury resulting from direct trauma during dissection, neuroma formation after neurotomy, or nerve compression caused by ligatures, staples, or mesh implantation (Hu et al., 2023; Reinpold, 2017; Carreño-Sáenz et al., 2024; Graham et al., 2018; Zanghi et al., 2024).

Despite the efficacy of prosthetic materials, the use of synthetic mesh is frequently associated with complications, including chronic pain, inflammatory responses, adhesion formation, and specific adverse effects on the male reproductive system (Liu et al., 2023; Tigora et al., 2025; Romano et al., 2025). Consequently, surgical strategies that explicitly target the precise handling and preservation of the neurovascular structures comprising the spermatic cord (SC) are crucial for enhancing patient quality of life after hernia repair (Reinpold, 2017; Schulster et al., 2017).

Anatomical and Functional Aspects of the Spermatic Cord

The integrity of the spermatic cord and surrounding neural elements is paramount in preventing significant post-operative morbidity (Graham et al., 2018). The SC is an intricate structure integral to male reproductive function, encompassing the vas deferens (VD), testicular and deferential arteries, veins (forming the pampiniform plexus), lymphatic vessels, and nerves (Collinge & Beltran, 2015; Yang et al., 2020). Anatomical studies confirm that injury to the SC, whether iatrogenic or traumatic, carries consequential risks for male sexual function, and bilateral injury presents the possibility of sterility (Collinge & Beltran, 2015).

Microscopic investigation reveals that the outermost layer of the SC structure comprises the external spermatic fascia (ESF) and the cremaster muscle (Yang et al., 2020). Within this sheath, the internal spermatic vessels and the VD are wrapped in two distinct, translucent sheaths: the internal spermatic fascia (ISF) and a smaller sheath termed the vas deferens fascia (Yang et al., 2020). The neural density within the SC is notably high, particularly around the vas deferens, and contains both sensory and sympathetic nerve fibers (Oka et al., 2016). Furthermore, detailed micro-anatomic

examinations indicate that many nerves are distributed ubiquitously across the SC tissues, except for the tubular structures, and their location is inconsistent (Yang et al., 2020).

In the inguinal region, surgeons must meticulously identify and protect the ilioinguinal nerve (IIN), the iliohypogastric nerve (IHN), and the genital branch (GB) of the genitofemoral nerve (GFN) (Messias et al., 2024; Firoozabadi et al., 2015). These nerves are highly vulnerable to surgical trauma, manipulation, entrapment, or scarring, leading directly to neuropathic CPIP (Firoozabadi et al., 2015; Graham et al., 2018; Zanghì et al., 2024). Surgeons performing open inguinal hernia repair typically use a nerve-preserving strategy, with meta-analyses indicating that the IIN is identified in 82% of surgeries, the IHN in 62%, and the GFN in 41% (Moseholm et al., 2023).

Clinically, the anatomical intimacy of the SC with the pubic tubercle predisposes it to injury during clamping procedures (Collinge & Beltran, 2015). The presence of abnormalities like hernias or lipomas results in a significantly increased average cord diameter, measured at 24.9 mm, compared to 16 mm in normal cords (Firoozabadi et al., 2015). Post-hernioplasty complications related to SC compromise include obstructive azoospermia due to vasal obstruction caused by mesh constriction or fibrosis (Shin et al., 2005), testicular ischemia potentially progressing to necrosis and requiring orchiectomy (Özsağır et al., 2019), and dysejaculation, often linked to compression of the vas deferens or SC structures by mesh or fibrotic tissue (Ece & Yılmaz, 2018). Moreover, the direct interaction of prosthetic material, such as polypropylene (PP) mesh, has been observed to cause permanent damage to the spermatic cords and testicles in experimental settings (Liu et al., 2023). The inflammatory reaction induced by PP mesh shortly after implantation is highly correlated with the appearance of tissue adhesions, obstruction of the spermatic cord, orchiatrophy, and reproductive system abnormalities (Liu et al., 2023). These early injuries induced by PP mesh are often persistent and irreversible (Liu et al., 2023).

Conventional Techniques and Their Limitations

The history of hernia management highlights a continuous effort to minimize anatomical tension (Tigora et al., 2025). Before the tension-free era, landmark operations included the Bassini repair and the McVay repair, which employed direct suture techniques to close the defect but were consistently hampered by high recurrence rates due to mechanical strain on the tissue (Olanrewaju et al., 2023; Tigora et al., 2025). The paradigm shifted dramatically in 1989 when Lichtenstein introduced the concept of tension-free prosthetic repair, utilizing a mesh implant to reinforce the inguinal canal floor (Lichtenstein et al., 1989; Tigora et al., 2025; Amid et al., 2004).

The Lichtenstein tension-free hernioplasty remains the most frequently performed surgical procedure globally and is often cited as the preferred anterior approach for IH repair using mesh (Messias et al., 2024; Hu et al., 2023; Köckerling & Simons, 2018; Romanowska et al., 2016; Amid et al., 2004). The core principle involves positioning a polypropylene mesh to reinforce the posterior inguinal wall without tension, utilizing intra-abdominal pressure to secure the repair (Messias et al., 2024; Amid et al., 1993).

Despite its success in reducing recurrence, the open anterior approach introduces several limitations. Standard polypropylene (PP) mesh, while possessing desirable properties like strength and flexibility, is prone to causing chronic inflammation, pain, and adhesion (Liu et al., 2023). The inflammatory response associated with the foreign body reaction, particularly involving heavy-weight synthetic meshes, contributes significantly to chronic discomfort and can directly impede the

function and structure of the adjacent spermatic cord (Liu et al., 2023; Rutegård et al., 2018). Furthermore, the open approach necessitates more extensive tissue damage and manipulation of the spermatic cord and cremaster muscle, increasing the risk of mechanical or inflammatory injury to these vital structures (Carreño-Sáenz et al., 2024). The major drawback of the open anterior approach, compared to laparoscopic techniques, is a higher association with CPIP (Olsson et al., 2016; Carreño-Sáenz et al., 2024).

A significant area of controversy within open repair concerns nerve management—specifically, routine ilioinguinal neurectomy (ING) versus nerve preservation (Hu et al., 2023; Reinpold, 2017). Meta-analysis findings reveal that ING can effectively reduce the incidence of severe pain on the first postoperative day, as well as increase the incidence of no pain at one and six months postoperatively, compared to nerve preservation (Hu et al., 2023). Nevertheless, ING is concurrently associated with a higher incidence of numbness during the early postoperative phase (Hu et al., 2023). General prophylactic neurectomy is widely discouraged by current guidelines, as overall meta-analyses indicate it does not reliably reduce CPIP risk and introduces sensory loss, which is itself a contributor to chronic pain (Reinpold, 2017). Prospective data suggests that mobilization and preservation of the IIN within a Lichtenstein repair, which often leads to mesh contact with the nerve, was an independent significant risk factor for chronic pain after five years (Reinpold, 2017; Reinpold et al., 2011). This insight supports the concept that allowing mesh/nerve contact is detrimental and that resecting a damaged nerve (pragmatic neurectomy) may sometimes be a superior approach compared to leaving an injured nerve *in situ* (Reinpold, 2017).

Minimally Invasive and Mesh-Based Innovations

The rise of minimally invasive surgery (MIS), particularly the laparoscopic approaches, Transabdominal Preperitoneal (TAPP) and Totally Extraperitoneal (TEP) repair, represents a major technical innovation (Bracale et al., 2018; Köckerling & Simons, 2018; Wei et al., 2015; Tigora et al., 2025; Arrey et al., 2025). These minimally invasive methods minimize surgical trauma, resulting in reduced postoperative pain, shorter hospitalization, and faster recovery compared to open repairs (Tigora et al., 2025; Romano et al., 2025; Arrey et al., 2025). Laparoscopic hernia repair (LHR) is generally associated with a significantly lower likelihood of chronic inguinal pain (OR = 0.28, 95% CI [0.30–0.56]) compared to open Lichtenstein repair (Carreño-Sáenz et al., 2024; Scheuermann et al., 2017). This reduction in CPIP is largely attributed to the decreased tissue trauma and less extensive dissection of the spermatic cord and cremaster muscle required in MIS techniques (Carreño-Sáenz et al., 2024). While TAPP offers the advantage of superior visualization of the abdominal cavity and potential hernia defects, TEP minimizes the risk of intra-abdominal complications as it avoids peritoneal entry (Ozel & Kara, 2024). Both TAPP and TEP maintain recurrence rates comparable to the Lichtenstein technique (Carreño-Sáenz et al., 2024). Further technological advancement introduced robotic-assisted surgery, which offers enhanced dexterity, visualization, and precision, although this approach is typically associated with longer operative times and higher costs compared to standard laparoscopy (Huerta et al., 2019; Arrey et al., 2025).

Simultaneously, material science innovations addressed mesh-related complications. The evolution transitioned towards lightweight and macroporous meshes, designed to reduce inflammatory response and lower the incidence of chronic pain and foreign body sensation (Tigora et al., 2025). For open Lichtenstein repair, the consensus suggests recommending lightweight mesh

over heavyweight mesh, as lightweight mesh may be associated with less chronic pain (Bakker et al., 2020; Uzzaman et al., 2012). However, clinical comparisons reveal varying results; for instance, in laparoscopic TEP repair, certain studies observed no differences in pain outcomes between lightweight and heavyweight meshes, but did report an increase in recurrence rates with the lighter material (Xu & Xu, 2019; Hu et al., 2019). Studies regarding the association of chronic pain with heavyweight standard polypropylene mesh show varying outcomes (Melkemichel et al., 2020; Rutegård et al., 2018).

Mesh selection and fixation techniques are critical domains of innovation aimed at cord sparing. Anatomically configured three-dimensional (3D) meshes, such as the 3D MAX Light mesh, can be placed laparoscopically (TAPP/TEP) with minimal need for mechanical fixation, resulting in fewer complications (Tiwari et al., 2016). The use of traditional mechanical fixation methods (sutures or staples/tacks) carries the risk of nerve entrapment and subsequently, chronic pain (Tiwari et al., 2016; Tigora et al., 2025). Consequently, there is a trend toward non-fixation or the use of atraumatic fixation (Tiwari et al., 2016). The use of self-fixating meshes or no mesh fixation at all is becoming common in advanced surgical practices (Tiwari et al., 2016). International guidelines generally advise against mesh fixation in most hernia types, although fixation may be recommended for large medial defects (EHS M3 classification) to reduce recurrence risk (Carreño-Sáenz et al., 2024). Alternative fixation methods, such as glues like fibrin sealant (FS) or n-butyl-2 cyanoacrylate (NB2C), have shown promise in open Lichtenstein repair with comparable short-term chronic pain and recurrence outcomes to sutures (Reinpold, 2017). Absorbable adhesives, such as fibrin sealants or cyanoacrylic glues, and self-gripping meshes have emerged as alternatives to reduce tissue trauma and potential nerve entrapment (Tigora et al., 2025). Crucially, in laparoscopic repair, mesh fixation using staples in the pain triangle, where nerves are located, is discouraged due to the risk of nerve damage (Carreño-Sáenz et al., 2024).

Cord-Sparing and Regenerative Techniques

True cord-sparing strategies focus on avoiding cord trauma and fostering a regenerative tissue response (Graham et al., 2018). The most explicit cord-sparing innovation identified is the microsurgically assisted inguinal hernia repair, a novel technique that integrates the use of high magnification typically reserved for fertility procedures (Schulster et al., 2017). This method enables superior anatomical visualization, allowing for meticulous identification and preservation of the nerves and spermatic cord structures, thereby preventing injury or entrapment by sutures (Schulster et al., 2017). Outcomes reported for this specialized technique included a 0% rate of chronic pain and vas injury at two-year follow-up (Schulster et al., 2017). Specific technical recommendations derived from this approach include avoiding mesh plugs in the internal ring defect, tightening a dilated internal ring with sutures, and ensuring the mesh patch includes a preformed 1.25 cm opening for the spermatic cord to prevent erosion into the vas deferens, which is a known cause of late vasal obstruction (Schulster et al., 2017; Shin et al., 2005).

In the context of open repair, a "nerve-minded" approach is crucial, involving the meticulous identification and preservation of the IIN, IHN, and GB of the GFN, which requires specialized anatomical knowledge and surgical expertise (Messias et al., 2024; Lange et al., 2016). The strategy of pragmatic neurectomy—resecting nerves that are visibly damaged or inevitably at risk of mechanical stress from the mesh—is currently favored by specialized surgeons over routine

prophylactic neurectomy, supporting the notion that mesh contact with a nerve mobilized from its native position must be avoided (Reinpold, 2017).

One protective method utilizes an electrospun fibrous membrane (FM) as a biocompatible physical barrier implanted alongside polypropylene (PP) mesh during repair (Liu et al., 2023). In experimental models, the FM successfully shielded the spermatic cord from contact with the PP mesh, thereby reducing the damage caused by mechanical property mismatches and minimizing the early-stage inflammatory response (Liu et al., 2023). The FM itself completely degraded within 180 days, but critically, it promoted the peritonealization of the underlying PP mesh, resulting in fibrous tissue encapsulation that maintained a protective barrier for the spermatic cord structures post-degradation (Liu et al., 2023).

Another technique geared toward cord decompression and recurrence prevention in laparoscopic repair is the "TEP/TAPP plus" approach, involving the primary closure of the direct hernia defect using non-absorbable sutures to incorporate the pseudosac (Usmani et al., 2019). This technique demonstrated a statistically significant reduction in recurrence (0.9% vs. 4.4%) and seroma formation (6.4% vs. 12.6%) when compared to non-closure, suggesting an improved outcome likely due to structural support and reduced dead space adjacent to the cord (Usmani et al., 2019).

A parallel, highly innovative regenerative approach is embodied by the Stenting & Shielding (S&S) Hernia System, a device designed to achieve fixation-free obliteration of the hernia defect (Amato et al., 2024). Constructed from polypropylene-based Thermo-Polymer-Elastomer (TPE), the S&S device exhibits dynamic compliance, moving harmoniously with the abdominal wall musculature (Amato et al., 2024). This dynamic interaction is proposed to promote genuine tissue regeneration, fundamentally differing from the avascular fibrotic tissue typical of traditional static meshes (Amato et al., 2024). Experimental studies evaluating this device in a porcine model demonstrated massive neomyogenesis, along with extensive and maturing neo-angiogenesis and the development of new nerve structures (Amato et al., 2024).

The discussion of truly regenerative materials also remains nascent. Certain non-mesh techniques, such as the tension-free Desarda method, rely on the body's own tissue, specifically the external oblique aponeurosis, to reinforce the inguinal floor, achieving similar recurrence rates to Lichtenstein without introducing permanent foreign material (Aljubairy et al., 2017). Research points toward the use of absorbable biological materials, such as adipose-derived stem-cell-seeded non-cross-linked porcine acellular dermal matrix, aimed at promoting cellular and vascular infiltration in repairs (Iyyanki et al., 2015; Klinger et al., 2016). In the realm of biomaterials, biological meshes are pursued for their potential to reduce inflammation and enhance tissue integration (Olanrewaju et al., 2023). However, clinical efficacy in inguinal repair remains debated; a systematic review comparing porcine small intestinal submucosa (SIS) mesh versus PP mesh in open inguinal hernia repair found that the SIS group had a significantly lower incidence of discomfort, but simultaneously experienced a higher incidence of seroma (Köckerling et al., 2015; Nie et al., 2015). Moreover, the randomized, self-controlled BIOLAP trial comparing biological mesh to synthetic mesh in laparoendoscopic repair concluded that biological meshes did not reduce postoperative pain and were associated with significantly higher seroma and hernia recurrence rates, advocating for synthetic mesh as the continued standard of care in clean cases (Seefeldt et al., 2025).

Finally, the use of Platelet-Rich Therapies (PRP), as a mesh coating, is being investigated as a means to enhance regenerative healing (Anestiadou et al., 2024; Di Nicola, 2020). PRP coating of synthetic meshes promotes increased collagen deposition and improved inflammatory response, while on biological meshes, it increases tissue integration and neovascularization, suggesting a future route for accelerated healing and cord protection (Anestiadou et al., 2024).

Conclusion

The evolution of inguinal hernioplasty demonstrates a clear trend toward techniques that safeguard the spermatic cord and associated neurovascular structures, driven by the imperative to mitigate CPIP and preserve male fertility structures (Graham et al., 2018; Liu et al., 2023). While the introduction of tension-free mesh repair successfully mitigated hernia recurrence (Romanowska et al., 2016), attention has shifted entirely to minimizing mesh-induced morbidity, primarily chronic pain and reproductive system compromise (Liu et al., 2023).

Minimally invasive methods (TAPP and TEP) stand out as major innovations, consistently demonstrating lower chronic pain rates than the open Lichtenstein approach (Carreño-Sáenz et al., 2024; Scheuermann et al., 2017; Tigora et al., 2025). Within both open and laparoscopic fields, innovations centered on materials (lightweight and 3D meshes) and fixation (non-fixation or bio-adhesives) aim to reduce nerve and cord compression (Tiwari et al., 2016; Carreño-Sáenz et al., 2024).

The most precise cord-sparing innovation appears to be the microsurgically assisted hernia repair, which leverages high magnification to ensure meticulous avoidance of injury to the vas deferens and inguinal nerves, achieving exceptional outcomes in terms of minimal chronic pain (Schulster et al., 2017). Furthermore, innovations such as the electrospun fibrous membrane demonstrate a method to physically protect the cord and promote protective peritonealization in experimental models (Liu et al., 2023). Moving toward genuine regeneration, dynamic scaffolds like the S&S Hernia System offer a paradigm shift by converting the foreign body response into the proliferation of new muscle, nerves, and vessels in experimental models (Amato et al., 2024).

Despite these advancements, clinical data concerning biological and biosynthetic meshes still indicate a superior performance profile for conventional synthetic materials in non-contaminated inguinal repair, particularly regarding recurrence rates (Seefeldt et al., 2025). Further high-quality, randomized controlled trials are necessary to standardize and validate these cord-sparing approaches and regenerative scaffolds, ensuring that the enhanced short-term outcomes translate into enduring patient benefit (Usmani et al., 2019; Hu et al., 2023; Anestiadou et al., 2024; Tigora et al., 2025).

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