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A Narrative Review on Polypropylene Mesh Complications in Inguinal Hernia Repair - is Titanized Mesh an Option?

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Abstract

Introduction: Since the introduction of mesh in Inguinal Hernia Repair (IHR) the recurrence rate was lowered. Instead, postoperative pain which may be related to mesh side effects e.g. fibrosis, foreign body reaction, erosion and migration, and infection, has been recognized as the relevant outcome factor. The long-term effects of mesh and composite mesh need to be analyzed.

Methods: Pubmed, google scholar search using the search terms: polypropylene mesh, titanized mesh, TiMesh®; about polypropylene mesh the following terms: adhesion, erosion, infection, shrinkage, migration, seroma, degradation, pain; biocompatibility, foreign body reaction. Also, a bibliography of relevant articles and product-related information was searched.

Results: Mesh properties are determined by tensile strength, pore size, weight, reactivity and biocompatibility, elasticity, constitution, and shrinkage. PolyPropylene Mesh (PP) is associated with actual and long-term complications more than expected. These complications are associated with mesh structure-lightweight meshes showed fewer risks for complication as infection, pain, mesh migration, foreign body response, erosion, adhesion, shrinkage, pain, seroma, and recurrence. TiMesh® showed an advantage in in-vitro and animal studies which were supported by clinical studies. There is a shorter convalescence, and lesser foreign material sensitivity with comparable results in complications (Chronic pain, infection, recurrence).

Conclusion: Polypropylene mesh has been successful in inguinal hernia repair for decades. However, in recent years complications of PP became evident in scientific reports and the public. Complications seem to be related to the material and structure of the mesh but also to the surgeon's expertise and patient's characteristics. It became evident that more complications appear long-term. The true rate of complications could be higher. There are a few clinical reports on titanium-coated mesh (TiMesh) in TAPP and TEP inguinal hernia repair. Experience with TiMesh in laparoscopic procedures long-term and open IHR are missing. Especially about the long-term effects of coating PP with titanium we need to have a better understanding of the interaction of soft tissue and mesh. There are promising results of pure titanium mesh for inguinal hernia repair which need to be confirmed in further controlled clinical studies.

Introduction

The use of polypropylene mesh for hernia repair has been published by Usher for the first time [1]. The EU trialist collaboration found that mesh is superior to suture technique in inguinal hernia repair about pain and recurrence [2]. However, mesh and fibrosis turned out to be responsible for pain and other disturbances. Contrary to the manufacturer's disclosures, synthetic materials polypropylene mesh is not without disadvantages and may cause complications [3]. In a report by Anna Collinson and Jessica, Fürst BBC reported on 26th September 2018 that hernia mesh complications affect more than 100,000 patients (complication rate 12-30%) during the last six years before the report in England. Up to 170,000 people who had hernia mesh implants in England over six years could face complications due to BBC's Victoria Derbyshire program [4]. According to this program, many types of hernia mesh implants are being used with little or no clinical evidence [5]. The lightweight mesh may be associated with less chronic pain but an increase in inguinal hernia recurrence [6]. The selection of the mesh depends on the patient's characteristics (age, underlying disease, defect size, preoperative pain). The surgeon should know about mesh properties that are relevant for the success of implantation and for avoiding complications related to mesh: tensile strength, pore size, weight, reactivity and biocompatibility, elasticity, constitution (monofilament, multifilament, patches), and shrinkage. Most complications in inguinal hernia repair with PP mesh are related to the mesh properties. Complications of meshes are infection, adhesion, erosion, shrinkage; migration; seroma, degradation, pain, and recurrence. There is a search for mesh that reduces the risk of complication. Titanized mesh demonstrated improvement in patient reactions to the implanted mesh.

Materials and Methods

Pubmed, google scholar search using the search terms: polypropylene mesh, titanized mesh, TiMesh®; about polypropylene mesh the following terms: adhesion, erosion, infection, shrinkage, migration, seroma, degradation, pain; biocompatibility, foreign body reaction. Also bibliogr,aphy of relevant articles and product-related information was searched.

Mesh Properties

Mesh properties are determined by tensile strength, pore size, weight, reactivity and biocompatibility, elasticity, constitution, and shrinkage [7].

Tensile Strength

Coughing and jumping generate maximum intra-abdominal pressure (170 mmHg; 32 N/cm), which makes it obvious that the tensile strength of meshes (100 N/cm) may not be advantageous [8].

Pore Size

The pore size is important for soft tissue ingrowth. Above 75um it allows infiltration by macrophages, fibroblasts, blood vessels, and collagen. This may help to avoid granuloma bridging and encapsulation. A scar plate formation in meshes with small pores leads to reduced flexibility [9].

Weight

The weight of the mesh depends on the weight of the polymer and the amount of material (Filament, pore size). Heavyweight Mesh (HWM) weighs 100 g/m, and Lightweight Mesh (LWM) typically 33g/m [10]. Reduced mesh material and decreased surface by large pores in LWM are responsible for less foreign body reaction [11]. According to a meta-analysis, LWM reduces pain and feeling of foreign body in Lichtenstein Inguinal Hernia Repair (IHR) [12]. However, LWM in the mesh plug technique may not induce less chronic pain [13]. LWM may also not cause an increased risk of recurrence in IHR compared to HWM [14]. HWM should be used in laparo-endoscopic repairs of direct or large inguinal hernias to reduce recurrence rates according to a meta-analysis by Bakker, et al. (2021). LWM provides no benefit in indirect hernias [15]. In a systematic review, HWM had a distinctive advantage over LWM in recurrence in laparoscopic IHR with equivalent outcomes in complications (postoperative pain, seroma, foreign body sensation, infection, numbness) [16].

Reactivity/Biocompatibility

The mesh material, e.g. Polypropylene (PP), is physically and chemically [17] inert, stable, non-immunogenic, and non-toxic but it may induce a foreign body reaction involving inflammation, fibrosis, calcification, thrombosis, and granuloma. The amount of material (Filament and pore size) is relevant for the reaction. Mesh may influence the collagen composition delaying the replacement of type III collagen by the stronger type I collagen [18]. The intensity of oxidative stress seems to be strongly related to the amount of implanted polypropylene [19]. Polypropylene multifilament mesh allows a higher acute inflammatory response compared to monofilament mesh [20]. A higher systemic inflammatory response was found after mesh repair compared with non-mesh repair and after open mesh, repair compared with laparoscopic mesh repair [21]. However, others have not confirmed this by comparing Lichtenstein and TEP IHR [22]. Myeloid cell-dependent inflammation may follow mesh implantation [23]. There is no evidence to suggest a causal relationship between being implanted with a PP mesh and the occurrence of autoimmune disorders [24]. The immune reaction due to mesh implantation may cause rejection long-term. However, the reason for rejection is largely unknown [25].

Elasticity

HWM (elasticity 4-16%) when compared to LWM (Elasticity of 20-35%) may restrict the distension of the abdominal wall [26]. The mismatch of mechanical properties between soft tissue and mesh, causing a permanent PP mesh deformation, may increase the risk of mesh failure [27].

Constitution

Constitution is formed by multifilament and monofilament fibers with multifilament fibers increasing the risk of infection [28].

Shrinkage

PP mesh may cause an inflammatory response, foreign body reaction, and scar tissue, which may be responsible for shrinkage [29]. Prosthetic meshes are not inert as claimed to be and can expand as well as shrink [30]. Shrinkage depends on both mesh properties-small pores producing scar tissue - and the anchoring device [31]. Mesh characteristics should be considered when choosing the mesh for IHR [32].

Mesh Complications

Complications of Anterior Inguinal Hernia Repair

In a meta-analysis, there was no difference between Prolene Hernia System® (PHS) and Lichtenstein IHR for recurrence, chronic pain, operating time, composite complication, and surgical reintervention [33]. Meta-analysis showed that Mesh-Plug Repair (MPR) requires a shorter operation time than Lichtenstein herniorrhaphy, and there is no significant difference in postoperative complications or recurrence rate [34]. This meta-analysis indicates that MPR mesh plug repair and PHS® seem comparable to LR Lichtenstein repair in terms of recurrence, chronic pain, time to return to work, inguinal paresthesia, testicular and scrotal problems, hematoma, seroma and wound infection. MPR and PHS® seem comparable in terms of recurrence, chronic pain, and wound infection [35].

Complications of Laparoscopic Inguinal Hernia Repair

A meta-analysis comparing Lichtenstein and TAPP indicates that the complication rate and outcome of both procedures are comparable. TAPP operation demonstrated only one advantage over Lichtenstein operation with significantly less chronic inguinal pain postoperatively [36]. TAPP was associated with a lower seroma rate, and TEP was associated with a lower edema rate according to a meta-analysis [37]. There was less early pain and fewer analgesics after TEP repair, compared to Lichtenstein repair with similar infection rates in this Randomized Controlled Trial (RCT) [38].

Mesh and Vessels

Mesh-induced inflammation and fibrosis may influence blood flow in arteries and veins [39]. Mesh fibrosis may not affect testicular flow [40]. However, dysejaculation and pain-related impairment of activity may be a complication of laparoscopic inguinal herniorrhaphy [41]. Tailored neurectomy, funicular release, and or mesh removal may be helpful [42]. In a recent systematic review, it has been stated that hernia repair with mesh-open or laparoscopic-does not affect male fertility [43].

Infection

Filament type and pore size are decisive factors for infection which may become apparent years after implantation. Meshes with monofilament and large pores reduce the risk of infection [44]. Polytetrafluoroethylene polymer, multifilament meshes, increased filament diameter, increased mesh weight, and smaller pore size increase bacterial adherence as does the addition of Prolene suture material [45] Risk factors for mesh infection are obesity, smoking, and diabetes [46]. There are reports of late-onset deep graft infection. With the more widespread use of mesh materials, this complication may become increasingly evident [47]. Peripheral blood inflammation markers predict surgical site infection after mesh inguinal hernia repair [48]. There is an increased risk of infection due to the larger size of mesh used in laparoscopic repair [49]. The incidence of mesh infection maybe 4.97%. Duration of surgery and mesh contamination is relevant to the incidence of mesh infection [50]. The risk of mesh infection following laparo-endoscopic IHR may persist for more than 5 years and probably as long as the mesh remains in the body [51]. In microbial adhesion tests (High-density Polypropylene Monofilament Mesh (PMM); Low-density PMM; prostheses composed of low-density polypropylene and a non-porous hydrophilic film (composite prostheses) depending on the type of bacteria collagen-coated hydrophilic prostheses with a large surface increased bacterial adherence [52]. Chronic mesh infection may be complicated by an enterocutaneous fistula [53]. Late-onset ileocutaneous fistula should be considered in case of inflammation and abscess formation even eight years after hernia repair [54] Delayed mesh infection may present 11 years after inguinal hernia mesh plug repair [55]. The infected mesh may be removed when conservative treatment fails open or laparoscopically [56,57].

Adhesion

All meshes induce adhesion. Absorption is reduced by ischemia, inflammation, and the foreign body. Pore size, filament structure, and the surface of the mesh structure are decisive in how much adhesion is produced when the mesh is placed in the vicinity of the bowel. Microporous structure at the side of the bowel and additional surface [58] in composite meshes provide a temporary

barrier against adhesion. However, the absorbable coatings may be degraded in the short term [59].

Erosion

Mesh erosion into intra-abdominal organs [60-62] is a serious long-term complication, which may be clinically apparent with unspecific symptoms. Mesh migration, adhesion, and formation of granulation tissue are relevant mechanisms [63] that may lead to enterocutaneous fistula [64]. Treatment of mesh erosion may be possible by a laparoscopic approach [65]. It is important to completely close the peritoneum when placing the mesh [66]. 23% of patients in a case series experienced early intestinal erosions occurring during the first 6 postoperative months while the remaining 67% occurred after 6 months. Patients presented most commonly with symptoms of acute obstruction followed by a palpable inguinal mass. The late presentation group after six months exhibited significantly more cases of mesh erosion when compared to the early presentation group. Early cases were more often associated with mesh fixation material erosion and symptoms of acute intestinal obstruction. An open primary procedure was more common in late cases while the early presentation was linked to laparoscopic procedures. Bowel resection was more frequently required in late cases [67].

Migration

IHR turned out to be the index operation in 62.9% (51.8% open repair, 42,9% laparoscopic, 1,8% robotic) of reports on mesh migration including polypropylene mesh and composite mesh affecting often multiple organs [68]. Mesh migration-induced colon inflammation or perforation can occur several months to 12 years following hernioplasty [69]. Mesh migration after laparoscopic inguinal hernia repair is more common after transabdominal preperitoneal repair as compared to Total Extraperitoneal (TEP) repair [70]. Mesh may be removed laparoscopically [71] Mesh migration may cause colocutaneous fistula [72], large scrotal hernia [73], mechanical bowel obstruction [74], small bowel volvulus [75], and mesh plug migration into the bladder [76]. Recommendations to avoid or reduce the risk of this complication: careful preperitoneal dissection to avoid/repair tears of the peritoneum; secure placement of mesh/mesh plug [77].

Mesh Fixation

A self-gripping mesh for hernia repair may result in less pain in the early postoperative phase but chronic post herniorrhaphy pain is not affected. Recurrence rates may be a potential disadvantage [78]. Mesh fixation with glue compared with sutures in Lichtenstein repair inguinal hernia is faster and less painful, without an increase in terms of recurrence rates in the long term [79] The self-gripping mesh and sutured mesh have a similar incidence of chronic postoperative inguinal pain, recurrence, and foreign body sensation. The main advantage of the self-gripping mesh is the consistently significantly reduced operation time [80]. Early and late recurrence was comparable between glue and suture fixation in open Lichtenstein IHR patients. Glue fixation had a shorter operating time and lower hematoma formation than suture fixation. Chronic pain and seroma formation were comparable [81]. In PP HWM or LWM, neither mechanical nor glue fixation improves the outcome of laparoscopic IHR. In HWM non fixation and LWM, fibrin glue fixation has been recommended [82]. There remains no superiority in terms of mesh fixation; the choice of fixation remains with the surgeon's expertise and the patient's preference [83].

Recurrence

The rate of recurrence has been reduced by the use of mesh. However, there are reports of recurrence after mesh inguinal hernia repair (13% of all herniorrhaphies worldwide). In most instances, the cause of recurrence is not the type of mesh, but inadequate fixation and underestimation of mesh shrinkage as the recurrent hernia occurs at the edge of the meshes (O'Dwyer). Patient risk factors are higher BMI, smoking, diabetes, and postoperative surgical site infections. Surgical risk factors are surgeon's experience, mesh with sufficient overlap, and surgical technique. Type of mesh and fixation of mesh were not significant factors for recurrence [84,85].

Pain

Although the tension-free technique of mesh inguinal hernia has been associated with less postoperative pain, Foreign Body Reaction (FBR) including nerve fibers and fascicles, neuromas at the interface of mesh and soft tissue suggest the destruction of nerves may be responsible for pain in IHR. Mesh with small pores induce a greater FBR leading to higher rates of chronic pain [86]. Despite the popularity and outcome of mesh repair persistent postoperative pain still occurs and may become more evident with the interest in laparoscopic hernia repair [87]. Removal of a meshoma must be considered as success rates are optimized following these measures [88]. The choice of the mesh or fixation method did not affect the overall long-term outcome, pain, or recurrence of the hernia. Less penetrating fixation (Glue or self-gripping mesh) is a safe option for the fixation of mesh in Lichtenstein hernia repair [89]. Early and late recurrence, chronic pain, and seroma formation were comparable between glue and suture fixation in open Lichtenstein IHR patients. Glue fixation had a shorter operating time and lower hematoma formation than suture fixation [90]. Intractable inguinal pain following laparoscopic inguinal hernia repair may be treated by laparoscopic mesh removal [91]. Surgical treatment should only be considered after adequate preoperative diagnostic evaluation of which the dermatome sensory mapping seems a useful tool for detailed neurophysiological assessment of patients with persistent post-herniorrhaphy pain undergoing remedial neurectomy [92].

Seroma

Any mesh type can cause seroma. However, large pore meshes are less likely to do so [93]. There may be a giant infected seroma following laparoscopic repair [94]. Mesh fixation with tacks or glue, a larger hernia defect, and medial defect localization presents a higher risk for seroma development in TAPP inguinal hernia repair [95]. Seroma formation is a natural process that cannot be completely prevented following laparoscopic inguinal hernioplasty, especially in patients with direct and large indirect inguinal hernias. Some intraoperative adjunctive techniques are effective in reducing clinically palpable seroma formation in select patients [96]. The simple technique of direct hernia defect closure with barbed suture in laparoscopic direct inguinal hernia repair is an effective method to reduce both incidence and volume of seroma formation without increasing the risk of recurrence, acute, and chronic pain [97].

Titanium Coated Mesh

Titanium coating of lightweight polypropylene mesh did not improve the biocompatibility compared to pure polypropylene mesh [98]. In an animal experiment comparing the development of adhesion of Proceed® mesh, Ultrapro® mesh, and TiMesh® the least formation of adhesion was noted in the TiMesh® group [99] Absorbable layers of Parietex Composite® and C-Qur® reduce the adhesion formation compared to TiMesh® and others in short term due to phagocytosis of absorbable coatings. There was insufficient incorporation of all meshes [100]. Barriers were demonstrated to reduce postoperative adhesion in animal experiments and showed positive results in humans according to a systematic review, but none of them has been used commonly worldwide. Titanized mesh has not been included in the evaluation [101] The design of titanium coated mesh (Biocer®) may be responsible for an increased recurrence after TAPP bilateral medial inguinal hernia repair [102]. Comparable functional results (recurrence), fewer postoperative complications (Seroma, foreign body sensation, sensitivity to weather changes), and improved quality of life can be achieved according to Horstmann, et al. (2006) by reducing the amount of PP in titanized meshes in TAPP inguinal hernia repair [103].

Author	Year	Procedure	Mesh	Results
Scheidbach [104]	2004	Animal experiment	Atrium® HWM, Vypro II® LWM, Parietene® LWM, TiMesh® ELWM	Foreign body reaction and biocompatibility of TiMesh® are favorable
Petter-Puchner [105]	2005	Animal experiment	TiMesh® ELWM, Vypro® + fibrin sealant (FS) versus staples	No failure in tensile and burst strength, good tissue integration, and neovascularization
Tamme [106]	2005	TEP	TiMesh	Chronic pain and rigidity – evaluation after one year necessary
Horstmann [103]	2006	TAPP	Prolene® Vypro® TiMesh®	Comparable functional results (recurrence), fewer postoperative complications (seroma, foreign body sensation, sensitivity to weather changes)
Harrell [108]	2006	In vitro experiment	Marlex®, PTFE, DualMesh Plus®, DualMesh®, Composix E/X®, Proceed®, Parietex Composite®, TiMesh®, Ultrapro®, Vypro®	DualMesh Plus® due to its antimicrobial coating demonstrated bactericidal properties,
Schug-Pass [107]	2006	Animal experiment	TiMesh® – Dual mesh® (expanded polytetrafluoroethylene)	TiMesh® is superior to DualMesh® in biocompatibility (adhesion, shrinkage, inflammatory response)
Fortelny [109]	2007	Animal experiment	TiMesh® + Glubran II®	Glubran II® impairs tissue integration, inflammation, and biomechanics of TiMesh®

Koch [110]	2008	Lichtenstein	TiMesh Standard PP mesh	Patients with the lightweight mesh had a shorter convalescence than those with the standard heavyweight mesh.
Fortelny [111]	2008	TAPP	Prospective – TiMesh® + Fibrin sealant (FS) Tisseel® Tissucuol®	Significant improvement in physical health and reduction of pain with SF36 and VAS
Peeters [112]	2010	TEP	RCT 1 year Vypro ll® – TiMesh® Marlex®	Negative influence on sperm motility by lightweight mesh
Schopf [113]	2011	TAPP	RCT Light TiMesh® Extralight TiMesh®	No difference in recurrence – chronic pain more in Light TiMesh®
Bittner [114]	2011	TAPP	RCT HVM extra light TiMesh® ELWM	ELWM - Less impairment of physical activity and seroma – no effect on chronic pain
Bittner [115]	2011	TAPP	RCT HWM MWM LWM TLW	HWM less postoperative convalescence but no effect on chronic pain – no difference in the LWM, MWM, TLWM
Schug-Pass [116]	2012	Experimental study	Fixation strength TiMesh® light, Ultrapro®, Optilene® – Tissucol®, Quixil®, Evicel®	No difference in fixation strength of different polypropylene meshes in an optimum combination with a fibrin glue
Fortelny [117]	2012	TAPP	TiMesh® Tisseel® Stapler	Comparable results for chronic pain and QoL
Schug-Pass [118]	2013	Experimental study	Fixation strength Evicel® Glubran®	Bioglue® and Glubran® improved adhesive strength
Köckerling [119]	2014	Evidence-based review of the literature	TiMesh®	In clinical studies, the titanium-coated polypropylene mesh shows in inguinal hernia repair certain benefits compared with the use of older heavy-weight meshes.
Peeters [120]	2014	TEP	RCT 3 years Vypro ll® TiMesh® Marlex®	No decrease of sperm motility – HVM and LWM comparable QoL, chronic pain, recurrence
Prassas [121]	2016	TEP	Retrospective LWM Titanium HWM	No difference in pain, chronic pain, recurrence
D'Amore [122]	2017	Animal experiment	DynaMesh®, TiMesh®, C-QUR/FX®	The meshes reduce but do not prevent adhesion
Köhler [102]	2018	TAPP	Bilateral mesh – TiO2 (Biocer®)	High recurrence rate – redesign of mesh recommended
Dong [123]	2018	Systematic review	Mesh nonmesh Vypro ll® TiMesh® Marlex®	Hernia repair with mesh in the open or laparoscopic procedure has no significant effect on male fertility

Yang [124]	2019	TAPP	TiMesh® PPM RCT	No difference in seroma and foreign body sensation but shorter recovery period in TiMesh
Filiovic-Cugura [125]	2020	Animal experiment	Surgisis®, Vypro II®, TiMesh®	Surgisis® produced more inflammation, less granuloma formation, and fibrosis, but more signs of infection compared to TiMesh®
Wirth [126]	2020	TAPP	Fibrin glue versus staple fixation of extra light titanized mesh	No difference in perioperative complications, recurrence, and chronic pain
Abbreviations: HWM Heavyweight mesh; LWM lightweight mesh; ELWM extra lightweight mesh; TLWM Titanized lightweight mesh; PPM polypropylene mesh; RCT randomized controlled trial; TAPP Transabdominal Preperitoneal Hernia Repair; TEP Total Extraperitoneal Hernia Repair				

Table 1: In-vitro and animal experiments, clinical and randomized studies, and a systematic review including TiMesh®.

In-Vitro and Animal Studies With Timesh

TiMesh® shows favorable foreign body reaction, biocompatibility, no failure in tensile and burst strength, good tissue integration, and neovascularization [104,105]. TiMesh® is superior to DualMesh® in biocompatibility (adhesion, shrinkage, inflammatory response) [108]. DualMesh Plus® due to its antimicrobial coating demonstrated bactericidal properties [107]. No difference in fixation strength of different polypropylene meshes in an optimum combination with fibrin glue [116]. Bioglue® and Glubran® improved adhesive strength [118]. The meshes reduce but do not prevent adhesion [122]. Surgisis® produced more inflammation, less granuloma formation, and fibrosis, but more signs of infection than TiMesh® [125].

Clinical Studies in IHR with Timesh

In clinical mostly randomized controlled trials there were advantages of TiMesh® in IHR. Horstmann reported comparable functional results (recurrence), fewer postoperative complications (seroma, foreign body sensation, sensitivity to weather changes) in Prolene®, Vypro®, and TiMesh® [103], Fortelny indicated significant improvement in physical health and reduction of pain with SF36 and Visual Analog Scale (VAS) in TiMesh® and Fibrin Sealant (Tisseel®) [111]. A negative influence in sperm motility by lightweight mesh has been reported after 1 year postoperatively but not after three years in laparoscopic TiMesh® IHR [112, 120]. Hernia repair with mesh in the open or laparoscopic procedure has no significant effect on male fertility according to a systematic review by Dong 2018 [123]. No difference in recurrence but more chronic pain has been reported in Light TiMesh® in TAPP IHR [113]. The ELW IHR has been followed by less impairment of physical activity and seroma but no effect on chronic pain in TAPP comparing HVM to extra light TiMesh® ELW [114]. HWM had less postoperative convalescence time but no effect on chronic pain. There was no difference in the LWM, MWM, and TLWM in TAPP IHRs [115]. There were comparable results for chronic pain and QoL in TAPP (TiMesh® Tisseel® versus Stapler) [117]. No difference in pain, chronic pain, or recurrence was demonstrated in TEP IHR [121]. No difference in seroma and foreign body sensation but a shorter recovery period in TiMesh® TEP was reported by Yang et al. 2019 [124]. There was no difference in perioperative complications, recurrence , and chronic pain in TAPP IHR [126]. In clinical studies, the titanium-coated polypropylene mesh shows in inguinal hernia repair certain benefits compared with the use of older heavy-weight meshes [119].

Conclusion

Polypropylene mesh has been successful in inguinal hernia repair for decades. However, in recent years complications of PP became evident in scientific reports and the public. Complications seem to be related to the material and structure of the mesh but also to the surgeon's expertise and patient's characteristics. It became evident that more complications appear long-term. The true rate of complications could be higher. There are a few clinical reports on titanium-coated mesh (TiMesh) in TAPP and TEP inguinal hernia repair. Experience with TiMesh in laparoscopic procedures long-term and in open IHR is missing. Especially about the long-term effects of coating PP with titanium we need to have a better understanding of the interaction of soft tissue and mesh. There are promising results of pure titanium mesh which need to be confirmed in further controlled clinical studies.

References

1. Usher FC (1982) Technique for repairing inguinal hernias with Marlex mesh. Am J Surg 143: 382-384.
2. EU Hernia Trialists Collaboration (2002) Repair of groin hernia with synthetic mesh: meta-analysis of randomized controlled trials. Ann Surg 235: 322-332.
3. Hernia Mesh Side Effects | Various Complications & Treatments (drugwatch.com)
4. Hernia mesh complications ‚affect more than 100,000' - BBC News
5. Hernia mesh implants used ‚with no clinical evidence' - BBC News
6. O'Dwyer PJ, Kingsnorth AN, Molloy RG, Small PK, Lammers B, et al. (2005) Randomized clinical trial assessing impact of a lightweight or heavyweight mesh on chronic pain after inguinal hernia repair. Br J Surg 92: 166-170.
7. Brown CN, Finch JG (2010) Which mesh for hernia repair? Ann R Coll Surg Engl 92: 272-278.
8. Cobb WS, Burns JM, Kercher KW, Matthews BD, James Norton H, et al. (2005) Normal intraabdominal pressure in healthy adults. J Surg Res 129: 231-235.
9. Klinge U, Weyhe D (2014) Hernia surgery: minimization of complications by selection of the Correct Mesh. Chirurg 85:105-111.
10. Klinge U, Klosterhalfen B, Birkenhauer V, Junge K, Conze J, et al. (2002) Impact of polymer pore size on the interface scar formation in a rat model. J Surg Res 103: 208-214.
11. Klosterhalfen B, Junge K, Klinge U (2005) The lightweight and large porous mesh concept for hernia repair. Expert Rev Med Devices 2: 103-117.
12. Bakker WJ, Aufenacker TJ, Boschman JS, Burgmans JPJ (2020) Lightweight mesh is recommended in open inguinal (Lichtenstein) hernia repair: A systematic review and meta-analysis. Surgery 167: 581-589.
13. Krauß M, Heinzel-Gutenbrunner M, Krönung L, Hanisch E, Buia A (2020) Comparing large pore lightweight mesh versus small pore heavyweight mesh in open mesh plug repair of primary and recurrent unilateral inguinal hernia - A questionnaire study for a retrospective analysis of a cohort of elective groin hernia patients using propensity score matching. Int J Surg 75: 93-98.
14. Melkemichel M, Bringman SAW, Widhe BOO (2021) Long-term Comparison of Recurrence Rates Between Different Lightweight and Heavyweight Meshes in Open Anterior Mesh Inguinal Hernia Repair: A Nationwide Population-based Register Study. Ann Surg 273: 365-372.
15. Bakker WJ, Aufenacker TJ, Boschman JS, Burgmans JPJ (2021) Heavyweight Mesh Is Superior to Lightweight Mesh in Laparo-endoscopic Inguinal Hernia Repair: A Meta-analysis and Trial Sequential Analysis of Randomized Controlled Trials. Ann Surg 273: 890-899.
16. Wu F, Zhang X, Liu Y, Cao D, Yu Y, et al. (2020) Lightweight mesh versus heavyweight mesh for laparo-endoscopic inguinal hernia repair: a systematic review and meta-analysis. Hernia 24: 31-39.
17. Vats M, Pandey D, Saha S, Talwar N, Saurabh G, et al. (2017) Assessment of systemic inflammatory response after total extraperitoneal repair and Lichtenstein repair for inguinal hernia. Hernia 21: 65-71.
18. Junge K, Klinge U, Rosch R, Mertens PR, Kirch J, et al. (2004) Decreased collagen type I/III ratio in patients with recurring hernia after implantation of alloplastic prostheses. Langenbecks Arch Surg 389: 17-22.
19. Donati M, Brancato G, Grosso G, Li Volti G, La Camera G, et al. (2016) Immunological reaction and oxidative stress after light or heavy polypropylene mesh implantation in inguinal hernioplasty: A CONSORT-prospective, randomized, clinical trial. Medicine Baltimore 95: e3791.
20. DiVita G, Patti R, Sparacello M, Balistreri CR, Candore G, et al. (2008) Impact of different texture of polypropylene mesh on the inflammatory response. Int J Immunopathol Pharmacol 21: 207-214.
21. Kokotovic D, Burcharth J, Helgstrand F, Gögenur I (2017) Systemic inflammatory response after hernia repair: a systematic review. Langenbecks Arch Surg 402: 1023-1037.
22. Vats M, Pandey D, Saha S, Talwar N, Saurabh G, et al. (2017) Assessment of systemic inflammatory response after total extraperitoneal repair and Lichtenstein repair for inguinal hernia. Hernia 21: 65-71.
23. Heymann F, von Trotha KT, Preisinger C, Lynen-Jansen P, Roeth AA, et al. (2019) Polypropylene mesh implantation for hernia repair causes myeloid cell-driven persistent inflammation. JCI Insight 4: e123862.
24. Kowalik CR, Zwolsman SE, Malekzadeh A, Roumen RMH, Zwaans WAR, et al. (2022) Are polypropylene mesh implants associated with systemic autoimmune inflammatory syndromes? A systematic review. Hernia 26: 401-410.
25. Wales E, Holloway S (2019) The use of prosthetic mesh for abdominal wall repairs: A semi-systematic-literature review. Int Wound J 16: 30-40.
26. Junge K, Binnebösel M, Rosch R, Ottinger A, Stumpf M, et al. (2008) Influence of mesh materials on the integrity of the vas deferens following Lichtenstein hernioplasty: an experimental model. Hernia. 12: 621-626.
27. Li X, Kruger JA, Jor JW, Wong V, Dietz HP, et al. (2014) Characterizing the ex vivo mechanical properties of synthetic polypropylene surgical mesh. J Mech Behav Biomed Mater 37: 48-55.
28. Klinge U, Junge K, Spellerberg B, Piroth C, Klosterhalfen B, et al. (2002) Do multifilament alloplastic meshes increase the infection rate? Analysis of the polymeric surface, the bacteria adherence, and the in vivo consequences in a rat model. J Biomed Mater Res 63: 765-771.
29. Demiray O, Gonullu D, Lari Gedik M, Akyildiz Igdem A, Nihat Koksoy F (2019) Effects of suture tecnique on mesh shrinkage. Asian J Surg 42: 224-227.
30. Coda A, Bendavid R, Botto-Micca F, Bossotti M, Bona A (2003) Structural alterations of prosthetic meshes in humans. Hernia 7: 29-34.
31. Harsløf S, Zinther N, Harsløf T, Danielsen C, Wara P, et al. (2017) Mesh shrinkage depends on mesh properties and anchoring device: an experimental long-term study in sheep. Hernia 21: 107-113.
32. Deerenberg EB, Verhelst J, Hovius SER, Lange JF (2016) Mesh expansion as the cause of bulging after abdominal wall hernia repair. Int J Surg Case Rep 28: 200-203.
33. Decker E, Currie A, Baig MK (2019) Prolene hernia system versus Lichtenstein repair for inguinal hernia: a meta-analysis. Hernia 23: 541-546.

34. Yu M, Xie WX, Li S, Wang DC, Huang LY (2021) Meta-analysis of mesh-plug repair and Lichtenstein repair in the treatment of primary inguinal hernia. Updates Surg 73: 1297-1306.

35. Ran K, Wang X, Zhao Y (2020) Open tensionless repair techniques for inguinal hernia: a meta-analysis of randomized controlled trials. Hernia 24: 733-745.

36. Scheuermann U, Niebisch S, Lyros O, Jansen-Winkeln B, Gockel I (2017) Transabdominal Preperitoneal (TAPP) versus Lichtenstein operation for primary inguinal hernia repair-A systematic review and meta-analysis of randomized controlled trials. BMC Surg 17: 55.

37. Hung TY, Wu CC, Chen LS, Kang YN (2020) Safety of two common laparoscopic inguinal herniorrhaphy approaches: an updated systematic review with meta-analysis of randomized clinical trials. Transl Androl Urol 9: 2007-2021.

38. Matikainen M, Vironen JH, Silvasti S, Ilves I, Kössi J, et al. (2021) A randomized clinical trial comparing early patient-reported pain after open anterior mesh repair versus totally extraperitoneal repair of inguinal hernia. Br J Surg 108: 1433-1437.

39. Sulaimanov M, Genc V, Cakmak A, Orozakunov E, Akkus S, et al. (2010) The effects of polypropylene mesh on femoral artery and femoral vein in mesh repair. Hernia 14: 629-634.

40. Ramadan SU, Gokharman D, Tuncbilek I, Ozer H, Kosar P, et al. (2009) Does the presence of a mesh have an effect on the testicular blood flow after surgical repair of indirect inguinal hernia? J Clin Ultrasound 37: 78-81.

41. Bischoff JM, Linderoth G, Aasvang EK, Werner MU, Kehlet H (2012) Dysejaculation after laparoscopic inguinal herniorrhaphy: a nationwide questionnaire study. Surg Endosc 26: 979-983.

42. Verhagen T, Loos MJ, Scheltinga MR, Roumen RM (2016) Surgery for chronic inguinodynia following routine herniorrhaphy: beneficial effects on dysejaculation. Hernia 20: 63-68.

43. Dong Z, Kujawa SA, Wang C, Zhao H (2018) Does the use of hernia mesh in surgical inguinal hernia repairs cause male infertility? A systematic review and descriptive analysis. Reprod Health 15: 69.

44. Klinge U, Junge K, Spellerberg B, Piroth C, Klosterhalfen B, et al. (2002) Do multifilament alloplastic meshes increase the infection rate? Analysis of the polymeric surface, the bacteria adherence, and the in vivo consequences in a rat model. J Biomed Mater Res 63: 765-771.

45. Sanders D, Lambie J, Bond P, Moate R, Steer JA (2013) An in vitro study assessing the effect of mesh morphology and suture fixation on bacterial adherence. Hernia 17: 779-789.

46. Yang H, Xiong Y, Chen J, Shen Y (2020) Study of mesh infection management following inguinal hernioplasty with an analysis of risk factors: a 10-year experience. Hernia 24: 301-305.

47. Mann DV, Prout J, Havranek E, Gould S, Darzi A (1998) Late-onset deep prosthetic infection following mesh repair of inguinal hernia. Am J Surg 176: 12-14.

48. Zhuo Y, Cai D, Chen J, Zhang Q, Li X (2021) Pre-surgical peripheral blood inflammation markers predict surgical site infection following mesh repair of groin hernia. Medicine Baltimore100: e25007.

49. Panagiotopoulou IG, Richardson C, Gurunathan-Mani S, Lagattolla NR (2012) Infection of laparoscopically inserted inguinal hernia repair mesh following subsequent emergency open surgery: a report of two cases. Ann R Coll Surg Engl 94: e3-e4.

50. Pande T, Naidu CS (2020) Mesh infection in cases of polypropylene mesh hernioplasty. Hernia 24: 849-856.

51. Gukas ID, Massouh F (2011) Serious life-threatening complication 5 years after laparoscopic totally extraperitoneal hernia repair: case report and discussion of the literature. Hernia 15: 459-462.

52. Pérez-Tanoira R, Isea-Peña MC, Celdrán A, García-Vasquez C, Esteban J (2014) Bacterial adherence to different meshes used in abdominal surgery. Surg Infect Larchmt 15: 90-93.

53. Liu H, Liu X, Zheng G, Ye B, Chen W, et al. (2019) Chronic mesh infection complicated by an enterocutaneous fistula successfully treated by infected mesh removal and negative pressure wound therapy: A case report. Medicine Baltimore 98: e18192.

54. Zhang J, Hu Z, Lin X, Chen B (2021) Late-Onset Ileocutaneous Fistula Eight Years After Plug Repair With Polypropylene Mesh: A Case Report. Front Surg 8: 785087.

55. Ito H, Matsumoto K, Terauchi T, Kimata M, Lefor AK, et al. (2021) Delayed mesh infection after inguinal hernia repair: a case report. J Surg Case Rep 2021: rjab399.

56. Mikamori M, Kinjo A, Nakahara Y, Iwamoto K, Hyuga S, et al. (2022) Laparoscopic mesh removal for mesh infection related to pararectal incision of previous appendectomy after laparoscopic total extraperitoneal inguinal hernia repair: A case report. Asian J Endosc Surg 15: 368-371.

57. Jin C, Shen Y, Chen J (2020) Laparoscopic evaluation and management of 47 patients with late-onset mesh infection after inguinal hernioplasty. Hernia 24: 381-385.

58. Degheili JA, Aboul Hosn M, El Lakis M, Hallal AH (2015) Sigmoid to scrotal fistula secondary to mesh erosion: a rare complication of inguinal hernia repair in a patient on anticoagulation. BMC Surg 15: 94.

59. Schreinemacher MHF, Emans PJ, Gijbels MJ, Greve JW, Beets GL, et al. (2009) Degradation of mesh coatings and intraperitoneal adhesion formation in an experimental model. Br J Surg 96: 305-313.

60. Li J, Cheng T (2019) Mesh erosion into urinary bladder, rare condition but important to know. Hernia 23: 709-716.

61. Lange B, Langer C, Markus PM, Becker H (2003) Mesh penetration of the sigmoid colon following a transabdominal preperitoneal hernia repair. Surg Endosc17: 157.

62. Xue TM, Tao LD, Zhang J, Zhang PJ (2015) Mesh erosion causes small bowel obstruction: a rare complication of laparoscopic inguinal hernia repair: case description and review of literature. Hepatogastroenterology 62: 55-58.

63. Xie TH, Wang Q, Ha SN, Cheng SJ, Niu Z, et al. (2022) Mesh plug erosion into the small intestine after inguinal hernia repair: A case report. World J Clin Cases 10: 3944-3950.

64. Miller K, Junger W (1997) Ileocutaneous fistula formation following laparoscopic polypropylene mesh hernia repair. Surg Endosc 11: 772-773.

65. Mulleners G, Olivier F, Abasbassi M (2019) A minimally invasive treatment of an asymptomatic case of mesh erosion into the caecum after total extraperitoneal inguinal hernia repair. Acta Chir Belg 119: 176-181.

66. Asano H, Yajima S, Hosoi Y, Takagi M, Fukano H, et al. (2017) Mesh penetrating the cecum and bladder following inguinal hernia surgery: a case report. J Med Case Rep 11: 260.

67. Koliakos N, Papaconstantinou D, Nastos C, Kirkilesis G, Bompetsi G, et al. (2021) Intestinal erosions following inguinal hernia repair: a systematic review. Hernia 25: 1137-1145.

68. Cunningham HB, Weis JJ, Taveras LR, Huerta S (2019) Mesh migration following abdominal hernia repair: a comprehensive review. Hernia 23: 235-243.

69. Chan RH, Lee KT, Wu CH, Lin WT, Lee JC (2017) Mesh migration into the sigmoid colon mimics a colon tumor, a rare complication after herniorrhaphy: case report. Int J Colorectal Dis 32: 155-157.

70. Patel M, Shenoy C, Nagarajan G, Chandiramani V (2020) Mesh migration into the sigmoid colon after total extraperitoneal hernioplasty - Report of a case and review of the literature. J Minim Access Surg 16: 411-414.

71. Gang S, Kim MJ, Park JW, Ryoo SB (2021) Laparoscopic removal of mesh migrating into the sigmoid colon after Totally Extraperitoneal (TEP) laparoscopic inguinal hernia repair with positive faecal occult blood test. BMJ Case Rep 14: e237167.

72. Al-Subaie S, Al-Haddad M, Al-Yaqout W, Al-Hajeri M, Claus C (2015) A case of a colocutaneous fistula: A rare complication of mesh migration into the sigmoid colon after open tension-free hernia repair. Int J Surg Case Rep 14: 26-29.

73. Nowak DD, Chin AC, Singer MA, Helton WS (2005) Large scrotal hernia: a complicated case of mesh migration, ascites, and bowel strangulation. Hernia 9: 96-99.

74. Yamamoto S, Kubota T, Abe T (2015) A rare case of mechanical bowel obstruction caused by mesh plug migration. Hernia 19: 983-985.

75. Stout CL, Foret A, Christie DB, Mullis E (2007) Small bowel volvulus caused by migrating mesh plug. Am Surg 73: 796-797.

76. Ishikawa S, Kawano T, Karashima R, Arita T, Yagi Y, et al. (2015) A case of mesh plug migration into the bladder 5 years after hernia repair. Surg Case Rep 1: 4.

77. Lo DJ, Bilimoria KY, Pugh CM (2008) Bowel complications after Prolene Hernia System (PHS) repair: a case report and review of the literature. Hernia 12: 437-440.

78. Verhagen T, Zwaans WA, Loos MJ, Charbon JA, Scheltinga MR, et al. (2016) Randomized clinical trial comparing self-gripping mesh with a standard polypropylene mesh for open inguinal hernia repair. Br J Surg 103: 812-818.

79. Lin H, Zhuang Z, Ma T, Sun X, Huang X, et al. (2018) A meta-analysis of randomized control trials assessing mesh fixation with glue versus suture in Lichtenstein inguinal hernia repair. Medicine Baltimore 97: e0227.

80. Molegraaf M, Kaufmann R, Lange J (2018) Comparison of self-gripping mesh and sutured mesh in open inguinal hernia repair: A meta-analysis of long-term results. Surgery 163: 351-360.

81. Phoa S, Chan KS, Lim SH, Oo AM, Shelat VG (2022) Comparison of glue versus suture mesh fixation for primary open inguinal hernia mesh repair by Lichtenstein technique: a systematic review and meta-analysis. Hernia 26: 1105-1120.

82. Novik B, Sandblom G, Ansorge C, Thorell A (2022) Association of Mesh and Fixation Options with Reoperation Risk after Laparoscopic Groin Hernia Surgery: A Swedish Hernia Registry Study of 25,190 Totally Extraperitoneal and Transabdominal Preperitoneal Repairs. J Am Coll Surg 234: 311-325.

83. Rausa E, Asti E, Kelly ME, Aiolfi A, Lovece A, et al. (2019) Open Inguinal Hernia Repair: A Network Meta-analysis Comparing Self-Gripping Mesh, Suture Fixation, and Glue Fixation. World J Surg 43: 447-456.

84. Siddaiah-Subramanya M, Ashrafi D, Memon B, Memon M (2018) Causes of recurrence in laparoscopic inguinal hernia repair. Hernia 22: 975-986.

85. Ashrafi D, Siddaiah-Subramanya M, Memon B, Memon MA (2019) Causes of recurrences after open inguinal herniorrhaphy. Hernia 23: 637-645.

86. Agarwal BB, Agarwal KA, Mahajan KC (2009) Prospective double-blind randomized controlled study comparing heavy- and lightweight polypropylene mesh in totally extraperitoneal repair of inguinal hernia: early results. Surg Endosc 23: 242-247.

87. Heise CP, Starling JR (1998) Mesh inguinodynia: a new clinical syndrome after inguinal herniorrhaphy? J Am Coll Surg 187: 514-518.

88. Zwaans WA, Verhagen T, Roumen RM, Scheltinga MR (2015) Factors Determining Outcome After Surgery for Chronic Groin Pain Following a Lichtenstein Hernia Repair. World J Surg 39: 2652-2662.

89. Matikainen M, Vironen J, Kössi J, Hulmi T, Hertsi M, et al. (2021) Impact of Mesh and Fixation on Chronic Inguinal Pain in Lichtenstein Hernia Repair: 5-Year Outcomes from the Finn Mesh Study. World J Surg 45: 459-464.

90. Phoa S, Chan KS, Lim SH, Oo AM, Shelat VG (2022) Comparison of glue versus suture mesh fixation for primary open inguinal hernia mesh repair by Lichtenstein technique: a systematic review and meta-analysis. Hernia 26: 1105-1120.

91. Slooter GD, Zwaans WAR, Perquin CW, Roumen RMH, Scheltinga MRM (2018) Laparoscopic mesh removal for otherwise intractable inguinal pain following endoscopic hernia repair is feasible, safe and may be effective in selected patients. Surg Endosc 32: 1613-1619.

92. Beel E, Berrevoet F (2022) Surgical treatment for chronic pain after inguinal hernia repair: a systematic literature review. Langenbecks Arch Surg 407: 541-548.

93. Peiper Ch, Klinge U, Junge K, Schumpelick V (2002) Meshes in inguinal hernia repair. Zentralbl Chir 127: 573-577.

94. Aravind B, Cook A (2015) Intra-abdominal giant infected seroma following laparoscopic inguinal hernia repair. Hernia 19: 795-797.

95. Köckerling F, Bittner R, Adolf D, Fortelny R, Niebuhr H, et al. (2018) Seroma following Transabdominal Preperitoneal Patch Plasty (TAPP): incidence, risk factors, and preventive measures. Surg Endosc 32: 2222-2231.

96. Li J, Gong W, Liu Q (2019) Intraoperative adjunctive techniques to reduce seroma formation in laparoscopic inguinal hernioplasty: a systematic review. Hernia 23: 723-731.

97. Zhu Y, Liu M, Li J, Wang M (2019) Closure of Direct Inguinal Hernia Defect in Laparoscopic Hernioplasty to Prevent Seroma Formation: A Prospective Double-blind Randomized Controlled Trial. Surg Laparosc Endosc Percutan Tech 29: 18-21.

98. Junge K, Rosch R, Klinge U, Saklak M, Klosterhalfen B, et al. (2005) Titanium coating of a polypropylene mesh for hernia repair: effect on biocompatibilty. Hernia 9: 115-119.

99. Delibegovic S, Koluh A, Cickusic E, Katica M, Mustedanagic J, et al. (2016) Formation of adhesion after intraperitoneal application of TiMesh: experimental study on a rodent model. Acta Chir Belg 116: 293-300.

100. Schreinemacher MH, Emans PJ, Gijbels MJ, Greve JW, Beets GL, et al. (2009) Degradation of mesh coatings and intraperitoneal adhesion formation in an experimental model. Br J Surg 96: 305-313.

101. Waldron MG, Judge C, Farina L, O'Shaughnessy A, O'Halloran M (2022) Barrier materials for prevention of surgical adhesions: systematic review. BJS Open 6: zrac075.

102. Köhler G, Fischer I, Kaltenböck R, Mitteregger M, Seitinger G, et al. (2018) Critical evaluation of an innovative mesh for bilateral transabdominal preperitoneal (TAPP) repair of inguinal hernias. Hernia 22: 857-862.

103. Horstmann R, Hellwig M, Classen C, Röttgermann S, Palmes D (2006) Impact of polypropylene amount on functional outcome and quality of life after inguinal hernia repair by the TAPP procedure using pure, mixed, and titanium-coated meshes. World J Surg 30: 1742-1749.

104. Scheidbach H, Tamme C, Tannapfel A, Lippert H, Köckerling F (2004) In vivo studies comparing the biocompatibility of various polypropylene meshes and their handling properties during endoscopic Total Extraperitoneal (TEP) patchplasty: an experimental study in pigs. Surg Endosc 18: 211-220.

105. Petter-Puchner AH, Fortelny R, Mittermayr R, Ohlinger W, Redl H (2005) Fibrin sealing versus stapling of hernia meshes in an onlay model in the rat. Hernia 9: 322-329.

106. Tamme C, Garde N, Klingler A, Hampe C, Wunder R, et al. (2005) Totally extraperitoneal inguinal hernioplasty with titanium-coated lightweight polypropylene mesh: early results. Surg Endosc 19: 1125-1129.

107. Harrell AG, Novitsky YW, Kercher KW, Foster M, Burns JM, Kuwada TS, Heniford BT. In vitro infectability of prosthetic mesh by methicillin-resistant Staphylococcus aureus. Hernia 10: 120-124.

108. Schug-Pass C, Tamme C, Tannapfel A, Köckerling F (2006) A lightweight polypropylene mesh (TiMesh) for laparoscopic intraperitoneal repair of abdominal wall hernias: comparison of biocompatibility with the DualMesh in an experimental study using the porcine model. Surg Endosc 20: 402-409.

109. Fortelny RH, Petter-Puchner AH, Walder N, Mittermayr R, Ohlinger W, et al. (2007) Cyanoacrylate tissue sealant impairs tissue integration of macroporous mesh in experimental hernia repair. Surg Endosc 21: 1781-5.

110. Koch A, Bringman S, Myrelid P, Smeds S, Kald A (2008) Randomized clinical trial of groin hernia repair with titanium-coated lightweight mesh compared with standard polypropylene mesh. Br J Surg 95: 1226-1231.

111. Fortelny RH, Schwab R, Glaser KS, Puchner KU, May C, et al. (2008) The assessment of quality of life in a trial on lightweight mesh fixation with fibrin sealant in transabdominal preperitoneal hernia repair. Hernia 12: 499-505.

112. Peeters E, Spiessens C, Oyen R, De Wever L, Vanderschueren D, et al. (2010) Laparoscopic inguinal hernia repair in men with lightweight meshes may significantly impair sperm motility: a randomized controlled trial. Ann Surg 252: 240-246.

113. Schopf S, von Ahnen T, von Ahnen M, Schardey H (2011) Chronic pain after laparoscopic transabdominal preperitoneal hernia repair: a randomized comparison of light and extralight titanized polypropylene mesh. World J Surg 35: 302-310.

114. Bittner R, Schmedt CG, Leibl BJ, Schwarz J (2011) Early postoperative and one year results of a randomized controlled trial comparing the impact of extralight titanized polypropylene mesh and traditional heavyweight polypropylene mesh on pain and seroma production in Laparoscopic Hernia Repair (TAPP). World J Surg 35: 1791-1797.

115. Bittner R, Leibl BJ, Kraft B, Schwarz J (2011) One-year results of a prospective, randomised clinical trial comparing four meshes in Laparoscopic Inguinal Hernia Repair (TAPP). Hernia 15: 503-510.

116. Schug-Pass C, Jacob DA, Lippert H, Köckerling F (2012) Differences in biomechanical stability using various fibrin glue compositions for mesh fixation in endoscopic inguinal hernia repair. Surg Endosc 26: 3282-3286.

117. Fortelny RH, Petter-Puchner AH, May C, Jaksch W, Benesch T, et al. (2012) The impact of atraumatic fibrin sealant vs. staple mesh fixation in TAPP hernia repair on chronic pain and quality of life: results of a randomized controlled study. Surg Endosc 26: 249-254.

118. Schug-Pass C, Jacob DA, Rittinghausen J, Lippert H, Köckerling F (2013) Biomechanical properties of semi synthetic glues for mesh fixation in endoscopic inguinal hernia repair. Hernia 17: 773-777.

119. Köckerling F, Schug-Pass C (2014) What do we know about titanized polypropylene meshes? An evidence-based review of the literature. Hernia 18: 445-457.

120. Peeters E, Spiessens C, Oyen R, De Wever L, Vanderschueren D, et al. (2014) Sperm motility after laparoscopic inguinal hernia repair with lightweight meshes: 3-year follow-up of a randomised clinical trial. Hernia 18: 361-367.

121. Prassas D, Rolfs TM, Sirothia N, Schumacher FJ (2016) Lightweight Titanium-coated Mesh Versus Standard-Weight Polypropylene Mesh in Totally Extraperitoneal Inguinal Hernia Repair (TEP): A Cohort Analysis. Surg Laparosc Endosc Percutan Tech 26: e113-e116.

122. Amore L, Ceci F, Mattia S, Fabbi M, Negro P, et al. (2017) Adhesion prevention in ventral hernia repair: an experimental study comparing three lightweight porous meshes recommended for intraperitoneal use. Hernia 21: 115-123.

123. Dong Z, Kujawa SA, Wang C, Zhao H (2018) Does the use of hernia mesh in surgical inguinal hernia repairs cause male infertility? A systematic review and descriptive analysis. Reprod Health 15: 69.

124. Yang S, Shen YM, Wang MG, Zou ZY, Jin CH, et al. (2019) Titanium-coated mesh versus standard polypropylene mesh in laparoscopic inguinal hernia repair: a prospective, randomized, controlled clinical trial. Hernia 23: 255-259.

125. Filipović-Čugura J, Misir Z, Hrabač P, Orešić T, Vidović D, et al. (2020) Comparison of Surgisis, Vypro II and TiMesh in contaminated and clean field. Hernia 24: 551-558.

126. Wirth U, Saller ML, von Ahnen T, Köckerling F, Schardey HM, et al. (2020) Long-term outcome and chronic pain in atraumatic fibrin glue versus staple fixation of extra light titanized meshes in laparoscopic inguinal hernia repair (TAPP): a single-center experience. Surg Endosc 34: 1929-1938.