Heliyon 9 (2023) e17691

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

# Impact of titanium-coated polypropylene mesh on functional outcome and quality of life after inguinal hernia repair

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ARTICLE INFO

*Keywords:*
Surgical mesh
Inguinal hernia
Postoperative complication
Quality of life

ABSTRACT

*Objective:* This study aims to compare the clinical outcomes of complications, quality of life, and chronic pain between titanium-coated polypropylene mesh and polypropylene mesh after Lichtenstein or TAPP surgery.

*Methods:* A retrospective cohort study was conducted, involving patients who underwent inguinal hernia repair using Timesh light®, Optilene LP®, or 3DMax™ meshes between January 2020 and May 2022. Based on the surgical method, patients were divided into Lichtenstein and TAPP groups, and further categorized according to the type of mesh used. The primary endpoints assessed postoperative complications, postoperative pain, and postoperative quality of life. Secondary endpoints included postoperative sensation in the surgical area and postoperative recurrence rate.

*Results:* A total of 180 Lichtenstein procedures and 478 TAPP procedures were included in the analysis after propensity score matching. The findings revealed that patients with titanium-coated polypropylene mesh did not exhibit significant advantages in perioperative data. Within three months to one year after TAPP surgery, patients with the titanium-coated polypropylene mesh reported improved foreign body sensation during activities ($P = 0.002$) and a lower incidence of chronic pain ($P = 0.008$). However, after one year, these advantages of titanium-coated polypropylene mesh were no longer significant during activity or at rest. In the TAPP group, the titanium-coated polypropylene mesh depicted advantages in the single score of the SF-36 questionnaire.

*Conclusions:* The utilization of titanium-coated polypropylene mesh resulted in reduced foreign body sensation and chronic pain in activity within one year after TAPP surgery, significantly enhancing certain aspects of the patient's quality of life compared to polypropylene mesh.

## 1. Introduction

Inguinal hernia is a mass formed by abdominal organs protruding to the body surface through a defect in the inguinal region. The European Hernia Society (EHS) recommends open Lichtenstein surgery and laparoscopic hernia repair as standard surgical procedures for inguinal hernia [1]. Although both procedures exhibit similar long-term recurrence rates [2], laparoscopic hernia repair is favored due to reduced postoperative pain and faster recovery [3]. However, regardless of the surgical technique employed, hernia mesh is

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https://doi.org/10.1016/j.heliyon.2023.e17691
Received 13 March 2023; Received in revised form 24 June 2023; Accepted 26 June 2023
Available online 29 June 2023

widely used in inguinal hernia repair worldwide [4]. Mesh usage effectively shortens surgical duration, reinforces abdominal wall tissue, and significantly reduces postoperative recurrence rates, but it is also associated with complications such as infection, seroma, foreign body sensation and chronic pain at the surgical site [5–7]. Consequently, new meshes are continually being developed to reduce the occurrence of these postoperative complications.

While polypropylene has become the preferred material for external abdominal hernia repair due to its quite high mechanical properties, chemical stability, and compatibility with soft tissue [8,9], certain challenges remain, such as serious organ adhesion and organ erosion [4,10,11,]. Optilene LP® (B. Braun, Germany) is a lightweight mesh with a large pore structure, woven from polypropylene material. It is the basic polypropylene mesh that we use most often in our center, but it can only be used in open inguinal hernia repair surgery (Lichtenstein). 3DMax™ (C.R. Bard, America) is a heavyweight mesh with a medium pore structure, also woven from polypropylene material. Compared to the 2D structure of Optilene LP®, it incorporates a 3D preforming process during weaving and is specifically designed for laparoscopic inguinal hernia repair (TAPP). Timesh light® (PFM medical, Germany) is a lightweight mesh with a large pore structure, obtained by Plasma Activated Chemical Vapor Deposition (PACVD) method, where a special titanium compound is firmly bonded to the surface of the polypropylene material through a covalent bond (according to the manufacturer). Theoretically, it maintains the softness of polypropylene while improving its biological histocompatibility, hydrophilicity, and anti-adhesive properties [12]. Several studies have reported that the addition of a titanium coating to the surface of polypropylene mesh can effectively reduce the level of inflammatory response and minimize mesh shrinkage [13,14]. Its main difference from the other two polypropylene meshes used in the experiment is the addition of a titanium coating. It can be used in both open and laparoscopic inguinal hernia repair surgery. Currently, there are no clinical studies directly comparing titanium-coated polypropylene mesh with biological mesh. However, findings from some preclinical studies suggest that biological mesh tends to induce more pronounced inflammation and cell proliferation, and less intense granuloma formation and fibrosis [15]. Furthermore, the infection rate associated with biological mesh has been reported to be higher than that of titanium-coated polypropylene mesh [15]. Another study has also indicated that biological mesh is associated with decreased surface coverage with adhesions but significantly increased shrinkage [16]. In contrast to comparing titanium-coated polypropylene mesh with other polypropylene composite meshes, there is no consistent conclusion regarding the anti-adhesion, anti-infection, and anti-shrinkage properties of various mesh types. This lack of uniformity can be attributed to the presence of different influencing factors across studies [17–21].

However, there are limited clinical studies on titanium-coated polypropylene mesh, and there is still controversy over whether titanium-coated polypropylene mesh has an advantage over polypropylene mesh in inguinal hernia repair [22–28]. Although titanium-coated polypropylene mesh has been used in many patients in China, there is a dearth of published data. Therefore, this retrospective study aims to compared the clinical effects of titanium-coated polypropylene mesh with two commonly used polypropylene meshes, which had not been used in any previous study. Our study contributes to the existing clinical research on titanium-coated polypropylene mesh, investigating the performance of the mesh in both TEP and TAPP surgeries. With a substantial sample size, our study provides reliable research conclusions. Meanwhile, our study yielded positive results by analyzing the data according to time subgroups.

## 2. Patients and methods

### 2.1. Study design

This retrospective, single-center cohort study included patients who underwent inguinal hernia repair with mesh at the Hernia Surgery Department of the First Affiliated Hospital of Chongqing Medical University in China from January 2020 to May 2022. Informed consent for the surgery was obtained from patients before an operation. The data and images presented in this article have been published with the informed consent of the patients. This study was approved by the Ethics Committee of the First Affiliated Hospital of Chongqing Medical University (approval number: 2022-K266, date: June 20, 2022).

The patients were divided into the Lichtenstein and TAPP groups according to the surgical method. Although the totally extraperitoneal (TEP) approach is also commonly used for inguinal hernia repair, due to the limited number of TEP cases in our center (only 13 cases during the study period) and the inherent differences between TEP and TAPP procedures, we did not include patients who underwent TEP surgery in order to minimize bias related to surgical technique. According to the mesh used during the surgery, the Lichtenstein group was further divided into the Ti–O group (Timesh light®, PFM medical, Germany) and PP group (Optilene LP®, B. Braun, Germany). Similarly, the TAPP group was further divided into the Ti-L group (Timesh light®, PFM medical, Germany) and PP-3D group (3DMax™, C.R. Bard, America). Table 1 provides an overview of the physical parameters of the three meshes. The selection of surgical methods and mesh types was determined through mutual communication between the surgeon and patient during preoperative consultation.

**Table 1**
The parameters of the meshes included.

| Mesh | Manufacturer | Filament | Polymer | Aperture ( mm ) | Weight ( g/m$^2$ ) |
|---|---|---|---|---|---|
| Timesh light® | PFM medical | Monofilament | Polypropylene + Titanium | 1.0 | 35 |
| Optilene LP® | B. Braun | Monofilament | Polypropylene | 1.0 | 36 |
| 3DMax™ | C.R. Bard® | Monofilament | Polypropylene (preforming) | 0.8 | 80–100 |

### 2.2. Patient selection

Patient selection criteria for this study were as follows: ① above 18 years old; ② use one of the three meshes for unilateral or bilateral Lichtenstein surgery or TAPP surgery. Exclusion criteria included: ① recurrent hernia; ② hernia operation combined with other surgeries, such as hysterectomy of round ligament, orchiectomy, enterectomy, etc.; ③ incarcerated hernia; ④ different types of meshes placed on both sides in bilateral hernias; ⑤ ASA score $\geq$4; ⑥ lost to follow-up.

#### 2.2.1. Surgical technique

All patients were in the supine position, and inhaled anesthesia combined with intravenous general anesthesia was used. Lichtenstein surgery or TAPP surgery was performed after successful anesthesia. All surgical procedures followed the standard protocol to ensure the preservation of nerve tissue [29–31], and various types meshes were utilized for hernia repair.

The standard Lichtenstein procedure was adhered to in our surgical approach [29,31]: the inguinal canal is opened and the hernia identified, and direct sacs were inverted by means of a single absorbable invaginating suture. The lower edge is tacked in place by a continuous suture of 3–0 prolene suture, which secures the mesh medially to the lacunar ligament and then proceeds laterally along Poupart's ligament beyond the internal ring. A slit in the mesh at the internal ring allows emergence of the spermatic cord. When thinning the cord, if the genitofemoral nerve cannot be clearly identified, the inferior cremaster muscle bundle containing the nerve and the external spermatic vessels may exit through a separate opening medial to the internal ring. The superior edge of the mesh is loosely secured by a similar continuous suture to the rectus sheath and conjoined muscle and tendon above. A single suture approximates the tails of the mesh to Poupart's ligament lateral to the internal ring. The external oblique aponeurosis was closed over the cord with a continuous absorbable suture.

During the standard TAPP procedure [30,32], pneumoperitoneum was induced and a 10 mm optic trocar was placed using an infra-umbilical incision, followed by placement of two 5 mm trocar in the left and right lateral abdomen in the midclavicular line. After inspection of the abdomen and exclusion of any injury related to access, an arcuated incision was made in the peritoneum from lateral of the inguinal ring to the median umbilical fold high above all possible hernia openings. The epigastric vessels were identified, and the medial and lateral compartments were dissected using blunt dissection in the avascular tissue. The rectus abdominis muscle, horizontal pubic ramus, Hesselbach's triangle, Cooper's ligament, and iliopubic tract were exposed. The peritoneum was dissected from the spermatic cord (round ligament in women) and in lateral hernias completely reduced and separated from the ductus deferens and testicular vessels. In direct hernias, the sac was completely dissected, and the hernia's orifice was freed from tissue; in large medial defects, the orifice was closed using an absorbable suture. The fascia spermatica and the nerves located in the parietal compartment were spared. After complete dissection, mesh was placed in a wrinkle-free manner with an overlap of all possible hernia openings by at least 3 cm. The mesh was fixated with four staples (Shanshi·Qi®, Beijing TransEasy Medical Tech. Co., Ltd) (suprapubic connective tissue in the midline, ligament of Cooper and one each medial and lateral of the epigastric vessels in the anterior abdominal wall) dispersed on the mesh. The peritoneum is closed using a running absorbable suture, and the trocar sites $\geq$10 mm are closed by suture of the fascia, and the skin is closed using 1–2 interrupted sutures.

All cases were performed by the same surgical team and conducted by two main surgeons following the standard procedures of Lichtenstein and TAPP. Basic nutritional support was provided to patients unable to consume food immediately after surgery until they could resume oral intake. In cases where postoperative incision infection was identified, corresponding antibiotic treatment was administered based on culture and sensitivity results, with a maximum duration of three days of continuous administration. None of the patients in our study received postoperative or post-discharge analgesic medication. Patients are discharged when their surgical incisions have healed well, there are no signs of infection such as redness or discharge, and they are able to move around on their own.

#### 2.2.2. Information collection

The following data was obtained from the electronic medical record system and outpatient follow-up: name, hospitalization number, age, gender, length of stay, height, weight, comorbidities, smoking habits, ASA, operation time, operation method, follow-up time, postoperative pain and short-term postoperative complications.

The complications were jointly determined by medical records and ASA, including respiratory diseases such as COPD, and circulatory diseases such as heart failure, diabetes, etc. Patients with severe comorbidities were excluded. Surgical site infection was defined as infection of the incision or mesh after Lichtenstein surgery. Seroma was defined as postoperative sterile exudation of the incision visible to the naked eye or effusion in the surgical area diagnosed by ultrasound (US) at the first postoperative outpatient follow-up (generally 30 days after surgery). The area not detected was recorded as 0 ml, which was determined by both clinical and ultrasonic examination.

The patients were followed up within two years after surgery, and the following information was obtained through outpatient follow-up, outpatient medical record system, and telephone inquiry: operating area, foreign body sensation, chronic pain, recurrence, quality of life, etc. The latest follow-up patient information was used in this study. The patient's responses about insensitive, stiff, or foreign body sensation in the surgical area were recorded as yes or no and a visual analog scale (VAS) was used to assess the pain status of patients ranging from 0 (painless) to 10 (the most painful imaginable). Surgical site stiffness usually refers to the patient's local muscle stiffness at the surgical site after surgery. The patient may feel that the muscles or soft tissues in the surgical area are in a tense and unnatural state, losing their original elasticity and flexibility. Surgical site foreign body sensation refers to an uncomfortable feeling that the patient may experience at the surgical site after surgery. The patient may report feeling the presence of a foreign body in the surgical area, similar to the sensation of a foreign object or obstruction. Chronic pain was defined as pain in the surgical area more than three months after the operation. Recurrence was defined as hernia recurrence at the original surgical site confirmed by

clinical and ultrasonic examination. Patients with symptoms (pain, swelling, etc.) were examined clinically first, and the US was performed (by a specialist radiologist) when the physical examination revealed suspicious findings. The SF-36 scoring scale [33] was used to evaluate the postoperative quality of life with eight sub-scores. Patients evaluated their status by answering questions. Some sub-scores may consist of two or more questions, each question assigned a specific score. The final score for each sub-score was calculated by weighted summation based on the designated weights for each question. Ultimately, the scores between the two groups of patients were compared.

### 2.3. Statistical analysis

Statistical analysis in this study was performed using the SPSS Statistics 26 software package. To address potential confounding bias and enhance the reliability of our findings, we employed propensity score (PS) matching [34]. PS matching is a widely accepted method in observational studies to balance covariates and minimize the impact of confounding variables on treatment comparisons. By matching cases based on their propensity scores, which represent the probability of receiving a specific treatment given their baseline characteristics, we aimed to achieve a more balanced distribution of covariates between the surgical groups. This approach helps to simulate a randomized controlled trial-like scenario, where treatment assignment is independent of observed confounders. Additionally, the implementation of PS matching methodology facilitates a significant mitigation of sample attrition, resulting in a maximal preservation of the sample size. Because of the uniform distribution of cases in the different surgical groups, a 1:1 matching was used directly without replacement using a greedy algorithm, a caliper distance of 0.1 standard deviations of the logit of the propensity score was performed. The following preexisting confounding factors were used for matching, as they are known to have possible affecting surgical outcome [35–37]: age (years), sex (male/female), body height (m), body weight (kg), American Society of Anesthesiologists (ASA) score (I–V), and operative side (unilateral and bilateral).

Shapiro–Wilk test was used for assessing normality. For data that were normally distributed, we described them using the mean ± standard (SD) deviation and conducted hypothesis testing using the *t*-test. For data that did not follow a normal distribution, we described them using the median and interquartile range (IQR) and conducted hypothesis testing using the non-parametric Mann-Whitney *U* test. To compare data on nominal or categorical data between groups, chi-square test and Fisher's exact test were used to analyze the small case numbers. P value $\leq 0.05$ were considered statistically significant.

## 3. Results

A total of 1051 patients were registered to have completed an inguinal hernia repair between January 2020 and May 2022. After excluding 191 patients who did not meet the inclusion criteria, 860 patients were included in the PS matching analysis (Fig. 1). Following the adjustment for confounding bias, perioperative data of 190 patients in the Lichtenstein group and 479 patients in the TAPP group were compared.

Fig. 2 illustrates the field of vision of two meshes used during TAPP. The titanium-coated polypropylene mesh exhibited a softer texture compared to the ordinary polypropylene mesh.

Regarding the baseline patient characteristics before PS matching (Table 2), differences were observed only in "BMI" and "operative side" among patients in different groups. During hospitalization, six cases of surgical site infection were observed in the

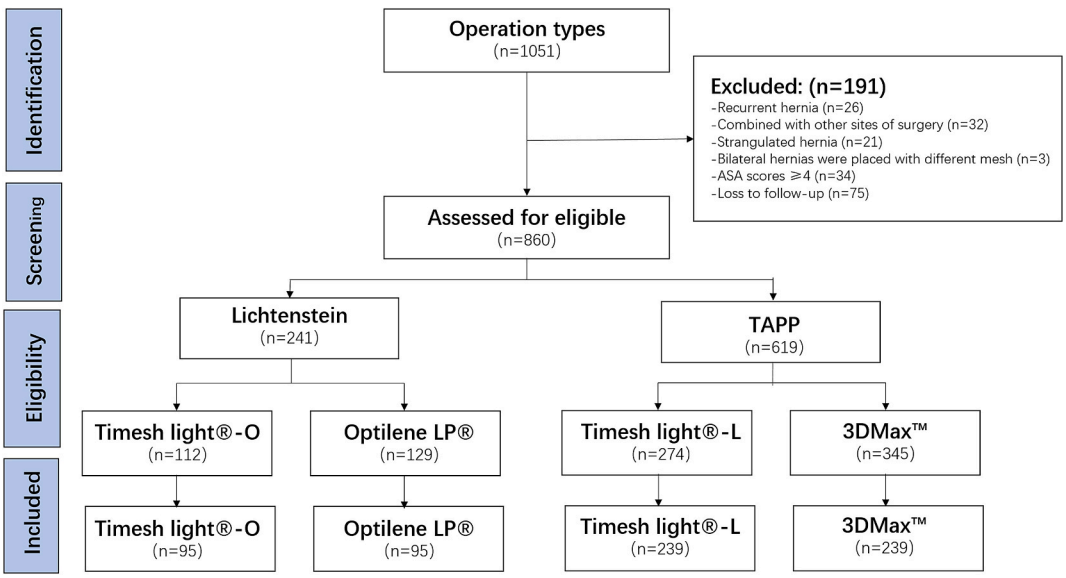


**Fig. 1.** The diagram of patient selection.

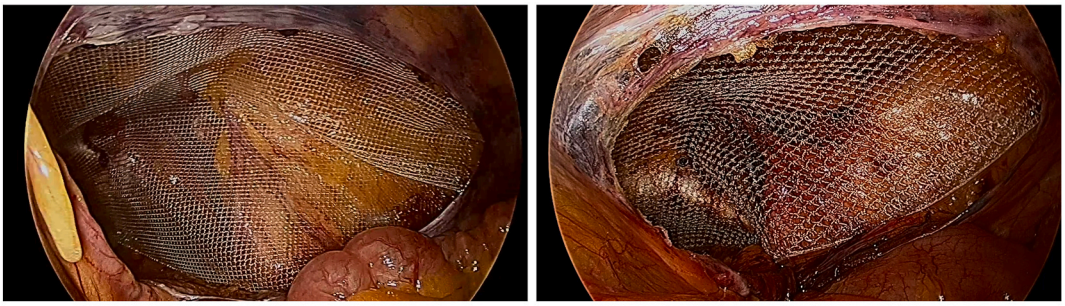


**Fig. 2.** Comparison of visual field between titanium-coated mesh and 3D-polypropylene mesh in TAPP procedure. (a): The field of visual field of titanium-coated polypropylene mesh; (b): The field of visual field of 3D-polypropylene mesh.

Lichtenstein group, all of which were simple surgical incision infections unrelated to the mesh and were treated with dressing changing and systemic antibiotics. There was no significant difference between Ti–O group (n = 2) and PP group (n = 4) ($P = 0.6883$), and no trocar or mesh-related infection were identified in the TAPP group.

At the first postoperative outpatient follow-up, seroma in the surgical area was recorded in 45 patients in the Lichtenstein group which was confirmed by US. However, there was no significant difference between the two subgroups ($P = 0.8686$). Compared to open surgery, the incidence of seroma after TAPP was reduced (n = 104). Although the incidence in the Ti-L group (15.69%) was slightly lower than in the PP-3D group (17.68%), there was no significant difference between the subgroups ($P = 0.5187$). After US diagnosis, severe patients were treated immediately with ultrasound-guided fluid extraction. The characteristics of the patients, surgical site occurrence and complications are presented in Table 2.

After a 1:1 PS matching, 190 cases in Lichtenstein group and 478 cases in TAPP group were included in the subsequent statistical analysis (Table 3). However, it was found that after PS matching, there was no statistically significant difference between the baseline data of all groups.

The surgical area was evaluated more than three months after the surgery through the outpatient follow-up system, inpatient medical record system, and telephone inquiries. During this process, not only the patients who did not completed the questionnaire, but also the matching cases were excluded. The sensation, chronic pain and over all VAS scores are illustrated in Table 4 and Table 5.

Finally, there were 156 patients (64.73%) in the Lichtenstein group completed the investigation. However, there was no statistically significant difference in any aspect between the two groups (Shown in Table 4).

**Table 2**
The characteristics of patients and postoperative complications before PS matching.

| | Lichtenstein | | | TAPP | | |
|---|---|---|---|---|---|---|
| Before | Ti–O | PP | P | Ti-L | PP-3D | *P* |
| | ( n = 112 ) | (n = 129) | | ( n = 274 ) | (n = 345) | |
| **Age** ( years ) ∅ | 65.00 (18–91) | 67.00 (22–90) | 0.4505 | 61.00 (18–90) | 65.00 (18–88) | 0.0618 |
| **Gender** | | | | | | |
| Female (%) | 9 (8.04) | 6 (4.65) | | 22 (8.03) | 30 (8.70) | |
| Male (%) | 103 (91.96) | 123 (95.35) | | 252 (91.97) | 315 (91.30) | |
| **ASA** | | | | | | |
| I | 73 | 89 | | 189 | 263 | |
| II | 30 | 23 | | 51 | 56 | |
| III | 9 | 17 | | 34 | 26 | |
| **BMI** ($kg/m^2$) ∅ | 24.23 (17.30–33.39) | 22.77 (16.61–34.19) | 0.0002* | 23.32 (17.10–33.71) | 22.76 (16.77–31.14) | 0.0041* |
| **Length of stay** (d) ∅ | 6.00 (3–16) | 6.00 (2–24) | 0.5179 | 4.00 (2–18) | 4.00 (2–15) | 0.4623 |
| **Smoking** (%)♯ | 43 (38.39) | 52 (40.31) | 0.7925 | 97 (35.40) | 139 (40.29) | 0.2435 |
| **DM** (%)♯ | 3 (2.68) | 5 (3.88) | 0.7276 | 12 (4.38) | 21 (6.09) | 0.3737 |
| **Side of operation**♯ | | | | | | |
| Bilateral (%) | 27 (24.11) | 31 (24.03) | 0.989 | 70 (25.55) | 133 (38.55) | 0.0008* |
| Unilateral (%) | 85 (75.89) | 98 (75.97) | | 204 (74.45) | 212 (61.45) | |
| **SSI** (%) ♯ | 2 (1.79) | 4 (3.10) | 0.6883 | | | |
| **Seroma** (%) ♯ | 20 (17.86) | 25 (19.38) | 0.8686 | 43 (15.69) | 61 (17.68) | 0.5187 |
| ≤3 ml | 13 | 14 | | 30 | 45 | |
| **>** 3 ml | 7 | 11 | | 13 | 16 | |

ASA, American Society of Anesthesiologists; BMI, body mass index; DM, diabetes mellitus; SSI, surgical site infection. ∅ Median (IQR) of the variables was used and compared by Mann-Whitney *U* test. ♯ Count (%) of the variables was used and evaluated by Chi-squared test. The level of significance was set at 0.05. * = P **<** 0.05.

**Table 3**
The characteristics of patients and postoperative complications after PS matching.

| | Lichtenstein | | | TAPP | | |
|---|---|---|---|---|---|---|
| After | Ti–O | PP | *P* | Ti-L | PP-3D | *P* |
| | ( n = 95 ) | (n = 95) | | ( n = 239 ) | (n = 239) | |
| Age ( years ) | 67.00 (18–91) | 67.00 (22–90) | 0.744 | 62.00 (18–90) | 63.00 (18–88) | 0.541 |
| Gender | | | | | | |
| Female (%) | 4 (4.21) | 5 (5.26) | | 21 (8.79) | 20 (8.37) | |
| Male (%) | 91 (95.79) | 90 (94.74) | | 218 (91.21) | 219 (91.63) | |
| ASA | | | | | | |
| I | 60 | 62 | | 168 | 175 | |
| II | 28 | 17 | | 47 | 38 | |
| III | 7 | 16 | | 24 | 26 | |
| BMI ($kg/m^2$) | 23.83 (17.30–33.39) | 23.53 (17.94.82–34.19) | 0.994 | 23.14 (17.10–33.71) | 23.18 (16.77–31.14) | 0.863 |
| Length of stay (d) | 6.00 (3–16) | 6.00 (2–21) | 0.565 | 4.00 (2–18) | 4.00 (2–15) | 0.739 |
| Smoking (%) | 37 (38.95) | 37 (38.95) | 1.000 | 84 (35.15) | 92 (38.49) | 0.448 |
| DM (%) | 3 (3.16) | 5 (5.26) | 0.473 | 11 (4.60) | 19 (7.95) | 0.131 |
| Side of operation | | | | | | |
| Bilateral (%) | 23 (24.21) | 20 (21.05) | 0.605 | 68 (28.45) | 59 (24.69) | 0.351 |
| Unilateral (%) | 72 (75.79) | 75 (78.95) | | 171 (71.55) | 180 (75.31) | |
| SSI (%) | 0 | 1 (1.05) | 0.447 | | | |
| Seroma (%) | 15 (15.789) | 16 (16.84) | 0.845 | 37 (15.48) | 35 (14.64) | 0.798 |
| ≤3 ml | 11 | 13 | | 23 | 24 | |
| > 3 ml | 4 | 3 | | 14 | 11 | |

ASA, American Society of Anesthesiologists; BMI, body mass index; DM, diabetes mellitus; SSI, surgical site infection. ∅ Median (IQR) of the variables was used and compared by Mann-Whitney *U* test. ♯ Count (%) of the variables was used and evaluated by Chi-squared test. The level of significance was set at 0.05. * = $P < 0.05$.

A total of 358 patients (57.84%) in the TAPP group completed the survey. Within three months to one year after surgery, patients who received titanium-coated polypropylene mesh reported better foreign body sensation during activity ($P = 0.020$). But, after one year, there were no significant difference between the two subgroups, either during activity or at rest. The incidence of chronic pain was higher in the 3D polypropylene mesh group within three months to one year after surgery, especially during activity ($P = 0.008$), while there was no significant difference between the two groups after one year. Also, there was no significant difference in the VAS between the subgroups (Shown in Table 5).

A total of 337 patients (104 in the Lichtenstein group and 233 in the TAPP group) completed the SF-36 questionnaire through telephone interview (or with the assistance of family members) (Shown in Table 6). In the Lichtenstein group, there were no significant difference between the two groups. In the TAPP group, Ti-L group showed obvious advantages only in Vitality ($P = 0.004$), Social Functioning ($P = 0.003$) and Reported Health Transition ($P = 0.048$).

**Table 4**
Effect and pain information of surgical area in the Lichtenstein groups.

| | 1 y~2 y | | | 3 m~1 y | | |
|---|---|---|---|---|---|---|
| Lichtenstein | Ti–O | PP | *P* | Ti–O | PP | *P* |
| | (n = 30) | (n = 51) | | ( n = 48 ) | (n = 27) | |
| **Surgical site stiffness** ( % ) | 0 | 2 (3.92) | 0.278 | 1 (2.08) | 3 (11.11) | 0.097 |
| **Foreign body sensation** ( % ) | | | | | | |
| at rest | 1 (3.33) | 0 | 0.194 | 0 | 2 (7.41) | 0.057 |
| at activity | 1 (3.33) | 0 | 0.194 | 3 (6.25) | 2 (7.41) | 0.85 |
| **Chronic pain** ( % ) | | | | | | |
| Pain at rest | 0 | 1 (1.96) | 0.447 | 0 | 0 | – |
| Pain at activity | 0 | 2 (3.92) | 0.278 | 1 (2.08) | 3 (11.11) | 0.097 |
| **VAS** | | | 0.982 | | | 0.176 |
| 0 | 15 | 24 | | 26 | 11 | |
| 1 | 14 | 14 | | 19 | 10 | |
| 2 | 1 | 1 | | 2 | 0 | |
| 3 | 0 | 1 | | 1 | 2 | |
| 4 | 0 | 0 | | 0 | 0 | |
| ≥5 | 0 | 0 | | 0 | 0 | |

VAS, Visual Analogue Score. The results are reported as count (%) and evaluated by Chi-squared test. The level of significance was set at 0.05. * = $P < 0.05$.

**Table 5**
Effect and pain information of surgical area in the TAPP groups.

| | 1 y~2 y | | | 3 m~1 y | | |
|---|---|---|---|---|---|---|
| TAPP | Ti-L | PP-3D | *P* | Ti-L | PP-3D | *P* |
| | ( n = 49 ) | (n = 107) | | ( n = 130 ) | (n = 72) | |
| **Surgical site stiffness** ( % ) | 0 | 2 (1.87) | 0.339 | 2 (1.35) | 2 (2.50) | 0.547 |
| **Foreign body sensation** ( % ) | | | | | | |
| at rest | 1 (2.04) | 2 (1.87) | 0.943 | 4 (2.70) | 5 (6.25) | 0.204 |
| at activity | 3 (6.12) | 4 (3.74) | 0.507 | 5 (3.38) | 9 (11.25) | 0.020* |
| **Chronic pain** ( % ) | | | | | | |
| at rest | 1 (2.04) | 1 (0.93) | 0.572 | 2 (1.35) | 2 (2.50) | 0.547 |
| at activity | 1 (2.04) | 2 (1.87) | 0.943 | 3 (2.03) | 8 (10.00) | 0.008* |
| **VAS** | | | 0.519 | | | 0.379 |
| 0 | 25 | 52 | | 56 | 29 | |
| 1 | 19 | 39 | | 25 | 23 | |
| 2 | 5 | 15 | | 14 | 11 | |
| 3 | 1 | 1 | | 2 | 0 | |
| 4 | 0 | 0 | | 1 | 1 | |
| ≥5 | 0 | 0 | | 0 | 0 | |

VAS, Visual Analogue Score. The results are reported as count (%) and evaluated by Chi-squared test. The level of significance was set at 0.05. * = $P < 0.05$.

**Table 6**
Postoperative SF-36 score of patients.

| | Lichtenstein | | | TAPP | | |
|---|---|---|---|---|---|---|
| SF-36 | Ti–O | PP | *P* | Ti-L | PP-3D | *P* |
| | ( n = 51 ) | (n = 53) | | ( n = 107 ) | (n = 126) | |
| **Total score** | 120.10 ± 4.17 | 119.48 ± 4.4.62 | 0.473 | 120.69 ± 4.36 | 120.32 ± 5.18 | 0.55 |
| 1~2 years | 118.80 ± 4.25 | 121.17 ± 3.85 | 0.686 | 119.00 ± 4.66 | 120.03 ± 6.12 | 0.347 |
| ≤1 year | 118.26 ± 5.27 | 121.49 ± 2.18 | 0.471 | 120.67 ± 3.71 | 121.83 ± 3.78 | 0.930 |
| **Individual score** | | | | | | |
| Physical functioning | 0.83 ± 0.15 | 0.86 ± 0.15 | 0.274 | 0.88 ± 0.15 | 0.89 ± 0.17 | 0.420 |
| Role Physical | 0.95 ± 0.11 | 0.95 ± 0.11 | 0.897 | 0.95 ± 0.10 | 0.95 ± 0.10 | 0.948 |
| Bodily Pain | 0.68 ± 0.10 | 0.67 ± 0.09 | 0.396 | 0.66 ± 0.09 | 0.66 ± 0.08 | 0.770 |
| General Health | 0.81 ± 0.08 | 0.78 ± 0.10 | 0.091 | 0.81 ± 0.07 | 0.79 ± 0.09 | 0.094 |
| Vitality | 0.69 ± 0.06 | 0.68 ± 0.05 | 0.312 | 0.69 ± 0.06 | 0.67 ± 0.05 | 0.004* |
| Social Functioning | 0.66 ± 0.05 | 0.66 ± 0.04 | 0.978 | 0.65 ± 0.05 | 0.67 ± 0.04 | 0.003* |
| Role Emotional | 0.91 ± 0.18 | 0.93 ± 0.16 | 0.508 | 0.93 ± 0.14 | 0.95 ± 0.12 | 0.468 |
| Mental Health | 0.67 ± 0.06 | 0.65 ± 0.06 | 0.183 | 0.66 ± 0.05 | 0.65 ± 0.06 | 0.849 |
| Reported Health Transition | 0.41 ± 0.13 | 0.42 ± 0.12 | 0.469 | 0.43 ± 0.13 | 0.40 ± 0.16 | 0.048* |

The results are reported as Mean ± SD and evaluated by *t*-test. The level of significance was set at 0.05. * = $P < 0.05$.

## 4. Discussion

The present analysis revealed that there were no significant difference between titanium-coated polypropylene mesh and ordinary polypropylene mesh in the short-term within our cohort. However, notable distinctions emerged in various aspects of performance with extended postoperative time. In the TAPP group, the titanium-coated polypropylene mesh exhibited varying degrees of advantage concerning postoperative foreign body sensation, chronic pain in the surgical area, and quality of life.

### *4.1. Surgery and mesh*

Lichtenstein and TAPP surgeries are internationally recognized as the gold standard methods for inguinal hernia repair. Partially absorbable mesh and biological mesh are associated with inflammatory reaction, and non-absorbable mesh is still the main component of hernia repair materials. Although ordinary polypropylene mesh, as the preferred mesh material, is lightweight and pliable, meeting the procedure and long-term placement of hernia repair materials, it is difficult to avoid rare but serious organ perforation. Consequently, continuous efforts are being made to develop various technologies and new materials to enhance the biocompatibility of ordinary polypropylene meshes.

In this study, three types of meshes were evaluated, all featuring a large-pore, monofilament structure. Optilene LP® is commonly used clinically and shares very similar physical parameters with Timesh light®. 3DMax™ mesh is a polypropylene mesh specially designed for laparoscopy surgery. Compared to ordinary polypropylene mesh, it is preformed and has a concave and convex radian designed according to the human abdominal wall, which can better fit the inguinal region, and it is about 60% lighter than the

traditional polypropylene mesh. Does titanium-coated polypropylene mesh yield better clinical effect than ordinary polypropylene mesh or the "optimized" polypropylene mesh? Our analysis revealed no significant differences between titanium-coated polypropylene mesh and ordinary polypropylene mesh used in the open Lichtenstein surgery. However, the titanium-coated polypropylene mesh demonstrated certain advantages after the laparoscopic TAPP surgery.

### 4.2. Perioperative outcome and long-time outcome

Patient prognosis serves as a vital endpoint in clinical trials and remains a focal point of mesh performance evaluation in this study. There was no significant statistical difference between the two groups in terms of the main postoperative prognosis (complications, recurrence, foreign body sensation, chronic pain, and postoperative weight of life) in the two studies [24,38], which also investigated th e performance of titanium-coated polypropylene mesh and ordinary polypropylene mesh after Lichtenstein surgery, similar to our results. Koch et al.'s study reported a shorter recovery period of patients with the titanium-coated polypropylene mesh compared to Prolene®, an ordinary polypropylene mesh, including the time to return to work (4 d vs. 6.5 d) ($P = 0.040$), and the time to return to normal activities (7 d vs. 10 d) ($P = 0.005$) [38]. This is in contrast to our study, in which the length of hospitalization for patients with the titanium-coated polypropylene mesh was slightly longer, although the results were not statistically significant. This difference may be attributed to the use of different types of ordinary polypropylene mesh. We employed a lightweight polypropylene mesh with a similar weight to the titanium-coated polypropylene mesh, while Koch et al. used a heavy polypropylene mesh in their study. Nonetheless, further clinical trials are warranted to verify our conjecture.

According to previous studies comparing titanium-coated polypropylene mesh with polypropylene mesh, the use of titanium-coated polypropylene mesh was associated with less serum swelling and foreign body sensation after TAPP surgery [23,26,27]. And previous studies reported no difference in the recurrence rate of the titanium-coated polypropylene mesh after TAPP (and TEP) [23,26,27,39,40]. They also consistently suggested that there was no difference in postoperative chronic pain between the titanium-coated polypropylene mesh and Prolene®. However, when chronic pain was analyzed based on rest and activity states, as well as different time periods, we discovered that the titanium-coated polypropylene mesh could significantly reduce the incidence of chronic pain during activity ($P = 0.008$), but the difference was no longer apparent after one year. Furthermore, a previous study compared the chronic postoperative pain of lightweight titanium-coated polypropylene mesh with ultra-lightweight titanium-coated polypropylene mesh showing that the reduced titanium compound loading from 35 $g/m^2$ to 16 $g/m^2$ improved chronic pain (5.3% for lightweight titanium-coated polypropylene mesh and 1.5% for ultra-lightweight titanium-coated polypropylene mesh, $P = 0.037$) [39]. However, no trial has yet compared the ultra-lightweight titanium-coated polypropylene mesh and ordinary polypropylene mesh, potentially due to the limited clinical use of ultra-lightweight titanium-coated polypropylene mesh.

### 4.3. Quality of life

Previous studies have reported varying degrees of improvement in patients' quality of life following surgery with the use of mesh [27,41]. Our study compared the postoperative quality of life of titanium-coated polypropylene mesh to polypropylene mesh, and found no significant difference between the two groups in either the total score or the single scores. However, the titanium-coated polypropylene mesh demonstrated significant superiority in three individual scores (Vitality, Social Functioning and Reported Health Transition) after TAPP surgery. We do not think this is a coincidence. The endoscopic technique can avoid certain consequences of open injury, such as infection and effusion, which are known to causes of postoperative abnormal sensation in the surgical area, thereby affecting patient's quality of life. Therefore, there is a substantial difference in the patient's quality of life between the two types of meshes when used in endoscopic procedures. We consider this to be an advantage of the titanium-coated polypropylene mesh, as US confirmed that there was more seroma in 3D-PP group after TAPP, and the incidence of the maximum depth of seroma $>3$ cm is higher in 3D-PP group.

### 4.4. Limitations and prospects

From the data we have collected, the patients with a "foreign body sensation" tend to be thinner, and were usually found in this part of the patients with "surgical site stiffness". Regarding recurrent hernia tissue, the main components were the non-absorbable mesh and the fibrous scar tissue. Scar shrinkage is a physiological reaction during scar maturation. Continuous water loss can reduce the scar area to 60% of its initial area, which can manifest as an increase in the ratio of collagen type I to collagen type III. In our animal experiments (presented in supplementary material), we placed the mesh were placed between the external oblique abdominal muscle and the internal oblique abdominal muscle in rabbits, as well as in the parietal peritoneum (anterior abdominal wall). After a 90-day observation period, we found that the contraction rate of the titanium-coated polypropylene mesh was significantly lower than that of the polypropylene mesh. Furthermore, analysis using Sirius Red staining revealed a smaller ratio of type I collagen to type III collagen in the surrounding tissue of the titanium-coated polypropylene mesh. Therefore, we think that the titanium-coated polypropylene mesh may induce less "surgical site stiffness" and "foreign body sensation" due to less fibrous tissue reaction caused by titanium-coated polypropylene mesh, as there is less shrinkage and stiffness, thereby improving the patient's comfort. However, this conjecture is completely based on animal experiments, necessitating further investigation in human studies to confirm this hypothesis. Moreover, the correlation analysis suggested that there was a correlation between seroma, surgical site stiffness, foreign body sensation and postoperative chronic pain. However, regression analysis did not provide conclusive evidence, warranting larger-scale studies to verify this association.

This retrospective study inherently carries limitations that cannot be completely eliminated, such as sample loss, recall bias, and confounding factors, even though we processed the data using propensity score matching. Meanwhile, based on social factors, not all patients were willing to complete all follow-up items, leading to some sample loss. We hope to see more clinical centers in China conducting multicenter prospective randomized controlled clinical trials in this area of study.

## 5. Conclusions

This is a study from China that provides clinical data on the performance of titanium-coated polypropylene mesh in inguinal hernia repair. Our study suggests that the titanium-coated polypropylene mesh reduced the patient's foreign body sensation and chronic pain in activity within one year after TAPP surgery, significantly improving certain aspects of the patient's quality of life compared to ordinary polypropylene mesh.

## Funding

This work was supported by the program of science and technology commission and healthcare commission (No. 2019MSXM057).

## Ethics approval and consent to participate

This study was approved by the Ethics Committee of the First Affiliated Hospital of Chongqing Medical University (approval number: 2022-K266, date: June 20, 2022). Written informed consents were obtained from the patients.

## Author contribution statement

Yelei Xiao: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Xiangyi Zuo: Performed the experiments; Analyzed and interpreted the data.

Huanhuan Li: Performed the experiments; Contributed reagents, materials, analysis tools or data.

Yu Zhao; Xuehu Wang: Conceived and designed the experiments.

## Data availability statement

Data included in article/supplementary material/referenced in article.

## Additional information

Supplementary content related to this article has been published online at [URL].

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Acknowledgements

Not applicable.

## References

[1] M. Miserez, et al., Update with level 1 studies of the European Hernia Society guidelines on the treatment of inguinal hernia in adult patients, Hernia 18 (2) (2014) 151–163.
[2] H.R. Langeveld, et al., Total extraperitoneal inguinal hernia repair compared with Lichtenstein (the LEVEL-trial), Ann. Surg. 251 (5) (2010) 819–824.
[3] J.-L. Dulucq, P. Wintringer, A. Mahajna, Laparoscopic totally extraperitoneal inguinal hernia repair: lessons learned from 3,100 hernia repairs over 15 years, Surg. Endosc. 23 (3) (2008) 482–486.
[4] D.M. Frey, et al., Randomized clinical trial of Lichtenstein's operation versus mesh plug for inguinal hernia repair, Br. J. Surg. 94 (1) (2007) 36–41.
[5] T. Clarke, et al., Fibrin glue for intraperitoneal laparoscopic mesh fixation: a comparative study in a swine model, Surg. Endosc. 25 (3) (2011) 737–748.
[6] C. Hollinsky, et al., Tensile strength and adhesion formation of mesh fixation systems used in laparoscopic incisional hernia repair, Surg. Endosc. 24 (6) (2010) 1318–1324.
[7] B.D. Masini, et al., Bacterial adherence to suture materials, J. Surg. Educ. 68 (2) (2011) 101–104.
[8] W. Hu, et al., Poly(dopamine)-inspired surface functionalization of polypropylene tissue mesh for prevention of intra-peritoneal adhesion formation, J. Mater. Chem. B 5 (3) (2017) 575–585.
[9] M. Fernandez-Gutierrez, et al., Low-density polypropylene meshes coated with resorbable and biocompatible hydrophilic polymers as controlled release agents of antibiotics, Acta Biomater. 9 (4) (2013) 6006–6018.
[10] P. Jarsaillon, Laparoscopic treatment of an umbilical hernia using a new composite mesh, Henia 4 (3) (2000) S17–S21.
[11] Ak. Pal, et al., Transrectal penetration of mesh afterendoscopic inguinal hernia repair: An unusual delayed complicationcomplication: A case report, Int J Abdom Wall Hernia Surg 4 (2021), 288–30.

[12] F. Köckerling, C. Schug-Pass, What do we know about titanized polypropylene meshes? An evidence-based review of the literature, Hernia 18 (4) (2014) 445–457.
[13] H. Scheidbach, et al., In vivo studies comparing the biocompatibility of various polypropylene meshes and their handling properties during endoscopic total extraperitoneal (TEP) patchplasty, Surg. Endosc. 18 (2) (2003) 211–220.
[14] H. Scheidbach, et al., Influence of titanium coating on the biocompatibility of a heavyweight polypropylene mesh, Eur. Surg. Res. 36 (5) (2004) 313–317.
[15] J. Filipović-Čugura, et al., Comparison of surgisis, vypro II and TiMesh in contaminated and clean field, Hernia 24 (3) (2020) 551–558.
[16] J.W. Burger, et al., Evaluation of new prosthetic meshes for ventral hernia repair, Surg. Endosc. 20 (8) (2006) 1320–1325.
[17] L. D'Amore, et al., Adhesion prevention in ventral hernia repair: an experimental study comparing three lightweight porous meshes recommended for intraperitoneal use, Hernia 21 (1) (2017) 115–123.
[18] V. Gómez-Gil, et al., Evaluation of synthetic reticular hybrid meshes designed for intraperitoneal abdominal wall repair: preclinical and in vitro behavior, PLoS One 14 (2) (2019), e0213005.
[19] M.H. Schreinemacher, et al., Degradation of mesh coatings and intraperitoneal adhesion formation in an experimental model, Br. J. Surg. 96 (3) (2009) 305–313.
[20] A. Celik, et al., The shrinking rates of different meshes placed intraperitoneally A long-term comparison of the TiMesh, vypro II, sepramesh, and DynaMesh, Surg. Laparosc. Endosc. Percutaneous Tech. 19 (4) (2009) e130–e134.
[21] C.G. Pereira-Lucena, et al., Experimental study comparing meshes made of polypropylene, polypropylene + polyglactin and polypropylene + titanium: inflammatory cytokines, histological changes and morphometric analysis of collagen, Hernia 14 (3) (2010) 299–304.
[22] E. Peeters, et al., Sperm motility after laparoscopic inguinal hernia repair with lightweight meshes: 3-year follow-up of a randomised clinical trial, Hernia 18 (3) (2014) 361–367.
[23] S. Yang, et al., Titanium-coated mesh versus standard polypropylene mesh in laparoscopic inguinal hernia repair: a prospective, randomized, controlled clinical trial, Hernia 23 (2) (2018) 255–259.
[24] C. Akalin, Long-term outcomes after Lichtenstein repair using titanium-coated mesh: a retrospective cohort study, Pakistan J. Med. Sci. 37 (1) (2021) 81–86.
[25] C. Akalin, O.O. Karagulle, The effects of onlay titanium-coated mesh on recurrence, foreign body sensation and chronic pain after ventral hernia repair, Asian J. Surg. 44 (9) (2021) 1158–1165.
[26] R. Bittner, et al., 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 (8) (2011) 1791–1797.
[27] R. Horstmann, et al., 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 (9) (2006) 1742–1749.
[28] E. Peeters, et al., Laparoscopic inguinal hernia repair in men with lightweight meshes may significantly impair sperm motility: a randomized controlled trial, Ann. Surg. 252 (2) (2010) 240–246.
[29] P.K. Amid, Lichtenstein tension-free hernioplasty: its inception, evolution, and principles, Hernia 8 (1) (2004) 1–7.
[30] W.W. Hope, W.S. Cobb, G.L. Adrales, Textbook of Hernia || the Gilbert Bilayer Connected Device (PHS) and Other Mesh Repairs, 2017, pp. 79–89, https://doi.org/10.1007/978-3-319-43045-4 (Chapter 11).
[31] I.L. Lichtenstein, et al., The tension-free hernioplasty, Am. J. Surg. 157 (2) (1989) 188–193.
[32] U. Wirth, et al., 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 (5) (2020) 1929–1938.
[33] J.E. Ware Jr., C.D. Sherbourne, The MOS 36-item short-form health survey (SF-36). I. Conceptual framework and item selection, Med. Care 30 (6) (1992) 473–483.
[34] G. Lonjon, et al., Potential pitfalls of reporting and bias in observational studies with propensity score analysis assessing a surgical procedure: a methodological systematic review, Ann. Surg. 265 (5) (2017) 901–909.
[35] H. Niebuhr, et al., What are the influencing factors for chronic pain following TAPP inguinal hernia repair: an analysis of 20,004 patients from the Herniamed Registry, Surg. Endosc. 32 (4) (2018) 1971–1983.
[36] F. Kockerling, et al., Seroma following transabdominal preperitoneal patch plasty (TAPP): incidence, risk factors, and preventive measures, Surg. Endosc. 32 (5) (2018) 2222–2231.
[37] F. Kockerling, et al., Does surgeon volume matter in the outcome of endoscopic inguinal hernia repair? Surg. Endosc. 31 (2) (2017) 573–585.
[38] A. Koch, et al., Randomized clinical trial of groin hernia repair with titanium-coated lightweight mesh compared with standard polypropylene mesh, Br. J. Surg. 95 (10) (2008) 1226–1231.
[39] S. Schopf, et al., Chronic pain after laparoscopic transabdominal preperitoneal hernia repair: a randomized comparison of light and extralight titanized polypropylene mesh, World J. Surg. 35 (2) (2011) 302–310.
[40] D. Prassas, et al., Lightweight titanium-coated mesh versus standard-weight polypropylene mesh in totally extraperitoneal inguinal hernia repair (TEP): a cohort analysis, Surg. Laparosc. Endosc. Percutaneous Tech. 26 (6) (2016) e113–e116.
[41] R.H. Fortelny, et al., The assessment of quality of life in a trial on lightweight mesh fixation with fibrin sealant in transabdominal preperitoneal hernia repair, Hernia 12 (5) (2008) 499–505.