Is polypropylene mesh material fundamentally safe for use as a reconstructive material in vaginal surgery: ICI-RS 2019?

Eric Rovner | Renaud de Tayrac | Ruth Kirschner-Hermanns | Nikolaus Veit-Rubin | Ralf Anding

1Department of Urology, Medical University of South Carolina, Charleston, South Carolina
2Department of Obstetrics and Gynecology, Caremeau University Hospital, Nimes, France
3Clinic of Urology-/Neuro-Urology, University Clinic Bonn, Germany
4Department of Obstetrics and Gynecology, Medical University of Vienna, Austria

Correspondence
Eric Rovner, Department of Urology, Medical University of South Carolina, Charleston, SC 29425.
Email: rovnere@musc.edu

Abstract
Polypropylene (PP) mesh has been used as a primary or adjuvant material for vaginal reconstruction for both stress urinary incontinence (SUI) and pelvic organ prolapse (POP) for decades. Whether polypropylene is the optimal material for such indications has been called into question by clinicians, regulatory agencies and the public in several countries around the world. This paper is a report of presentations and subsequent discussion at the annual International Consultation on Incontinence Research Society (ICI-RS) Meeting in June 2019 in Bristol, UK on the proposal “Is polypropylene mesh material fundamentally safe for use as a reconstructive material in vaginal surgery?” in which several of the salient issues were presented and discussed.

Keywords
mesh, polypropylene, stress urinary incontinence

1 | INTRODUCTION

Stress urinary incontinence (SUI) and pelvic organ prolapse (POP) are highly prevalent and bothersome conditions affecting a large number of individuals across the globe. A myriad of nonsurgical and surgical interventions have been developed to treat these conditions and yet it is generally accepted that the optimal solution has yet to be described. Polypropylene has been used in reconstructive surgery for more than 60 years in several forms including as suture material as well as a core component for the repair of hernias in numerous anatomical locations in the human body. Following the description of the Integral Theory and the treatment of SUI using the mid-urethral sling composed of type I polypropylene mesh, this material gained rapid acceptance and widespread utilization and with eventual expansion as a material for the repair of POP and SUI in the form of various commercially available kits. As such, type I polypropylene mesh has been applied as both a sling for the treatment of SUI and as an adjuvant material for the repair of vaginal prolapse for more than 20 years. Many commercially available products were approved for these indications with a concomitant increase in the total number of procedures being done. Hundreds of peer-reviewed publications have supported its use for the treatment of SUI, and indeed, it is probably the most studied surgical intervention for this indication.

Concomitant with the rapid adoption of mesh as a material for pelvic reconstruction there appeared multiple reports of complications associated with its use. Complications included pain, mesh exposure in the genital tract, mesh perforation into the urinary tract, infection, urinary tract obstruction, bleeding, visceral and nerve injury and even death, among others. These complications have occurred with mesh used for both SUI and POP, however, it appears that they are more common when used for the repair of POP with complication...
rates approaching 40% for this indication in some studies. As results have not been as favorable as a material for the repair of POP, the use of commercially available type I polypropylene mesh kits for the repair of POP has been halted in several countries around the world and several countries have also banned mesh for the treatment of SUI. Nevertheless, current high-level evidence supports Type I polypropylene mesh as an efficacious and durable surgical treatment for SUI.

The exact reasons for the increased reports of complications with the use of mesh in SUI and POP as compared to native tissue or other historical operations are unclear and very controversial. Such effects could be possibly related to the material itself, its effects in the human body or locally in the vagina, a systemic reaction to mesh implantation or degradation, or tissue-specific effects in the vagina and lower urinary tract. Some have suggested that the regulatory pathway for approval of these materials was inadequate and if well-done premarketing studies had been performed, such issues would have become manifest before widespread utilization. A recent evidence-based review by the International Consultation on Incontinence regarding some of these issues concluded that there is no evidence for a causative relationship between the implantation of mid-urethral slings with loosely woven polypropylene mesh and the development of systemic inflammation or aberrant host response.

There are other possible explanations for the mesh controversy unrelated to the material itself. It is difficult to rationalize that the rapid increase in reports of complications from PP mesh was simply coincidental with its increased utilization. Hence, one possibility is that widespread adaptation of mesh in the field of reconstruction led to inexperienced surgeons implanting the material. Such surgeons may have been inadequately trained in the techniques of implantation or patient selection for these surgeries with resulting in complications with a material that may or may not have a narrower safety margin than other historical surgeries for the same indication. Alternatively, it is possible that there is not an actual problem with type I polypropylene mesh, and that there is increased scrutiny with this material, or an increased number of cases being done which has led to an overall increase in the absolute numbers of complications but not in the actual incidence relative to other procedures.

In this paper, we touch on several of the salient issues regarding the safety of type I polypropylene mesh as a reconstructive material in the vagina. Clearly, there are many aspects of this controversy that cannot be completely discussed in this format given space limitations and emerging research.

2 | INTRINSIC MATERIAL CONSIDERATIONS REGARDING POLYPROPYLENE AS A SLING MATERIAL

2.1 | What is the physical/chemical construct of polypropylene that makes it suitable (or unsuitable) for use a sling material?

Only one human study has shown that polypropylene (PP) mid-urethral slings (MUS) induce a minimal inflammatory reaction without significant change in collagen solubility, in comparison to multifilament slings (Mersilene). These results were obtained from paraurethral connective tissue biopsies from 16 women with MUS (six Mersilene and 10 polypropylene), performed intraoperatively and after 2 years. However, an inflammatory reaction was not shown in the control group (paraurethral biopsies from four continents women with uterine bleeding irregularities, matched for age and parity).

Conversely, it has been shown in a urinary incontinence model in 144 adult female rats that PP MUS caused a more intense and longer-lasting inflammatory reaction with greater visceral penetration than an autologous fascial sling, up to 90 days after implantation.

The impact of PP mesh for prolapse has also been studied on the metabolism of the vaginal extracellular matrix in the rhesus macaque. Relative to sham, normal weight PP had a negative impact on the metabolism of both collagen and elastin, favoring catabolic reactions. However, lighter, more porous, and less stiff meshes had less of a negative impact.

2.2 | Polypropylene and risk of carcinogenesis and immunologic reaction

One study has been designed to assess whether there is any association between the implantation of PP MUS for the treatment of SUI and carcinogenesis. It was a nationwide cohort study based on the general female population in Sweden (20,905 exposed women). There were no significant differences in risk between exposed and unexposed women for pelvic organ cancers including ovarian (HR 0.8; 95% CI; 0.5-1.2), endometrial (HR 1.1; 95% CI; 0.8-1.4), cervical (HR 0.4; 95% CI; 0.2-1.0), bladder, and urethra (HR 0.7; 95% CI; 0.4-1.2).

Only one small histopathologic study in humans has suggested an immunologic reaction after PP MUS implantation. Seventeen women with vaginal MUS exposure and seven women with voiding difficulty or symptomatic pelvic organ prolapse (control group) underwent histopathologic evaluation and immunohistochemistry,
that revealed more CD 20+ cells in the persistent defective healing group than in the debridement or control groups \((P = .014\) and \(P = .014\), respectively), and differences in the ratios of T and B cells \((P = .035\) and \(P = .022\), respectively).

However, it is not possible to confirm that observed changes in the types of cells are linked to an immunologic reaction or to the MUS exposure itself.

### 2.3 Polypropylene and degradation

One study has suggested that PP mesh could be degraded after implantation.\(^1\) One hundred meshes explanted from patients with mesh-related complications were examined by electronic microscopy to evaluate the relative degradation characteristics of PP. Cracks on mesh surfaces were interpreted by authors as in vivo degradation, and these “degradation” findings were more frequently observed when the surrounding tissue reaction was classified as infection \((59\%\) of degraded PP samples with type 1 reaction vs \(20\%\) for type 3 reaction, \(P = .031\)).

To test that hypothesis, PP meshes were implanted in the incisional abdominal hernia model in Wistar rats and inoculated with *Escherichia coli*.\(^2\) After 30 days, meshes were explanted and washed with dimethyl sulfoxide (DMSO) and ultrasonic shock, then examined by environmental scanning electron microscope (ESEM). At the same time, PP meshes were inoculated in vitro with the same isolate of *E. coli*, then explanted after 2 to 15 days and washed with the same process. Superficial cracks were also observed, but these appeared to involve only the region with the biofilm, with no effect on the implant thread itself. Many authors, however, have come to the conclusion that polypropylene degradation may play a role in a continuous inflammatory response, resulting in mesh hardening and late deformations.\(^11\) However, these concepts remain very controversial and speculative based on limited evidence.

### 2.4 Is there a material that could potentially be a suitable substitute to the use of polypropylene mesh?

Several substitute materials have been studied, including long-lasting absorbable grafts, nonabsorbable grafts, and scaffolds for tissue engineering.

#### 2.4.1 Long-lasting absorbable grafts

Several studies have been conducted to compare the biocompatibility and duration of absorption of poly-lactic acid (PLA), a long-lasting absorbable polymer that has been extensively used in other surgical applications in humans, including orthopedics and visceral surgery. It has been shown that the PLA graft is biocompatible and has good mechanical properties at 3 months in the rat incisional hernia model. It allows a reduced inflammatory response and a better collagen organization compared to PP, both at 3 and 12 months. A new tissue could cover the defect with no recurrence of herniation.\(^22\) However, there are to date no vaginal implantations in humans.

Another long-lasting absorbable material \((\text{highly aligned collagen threads crosslinked using either genipin or 1-ethyl-3-(3-dimethylaminopropyl) carbodiimide and N-hydroxy succinimide (EDC/NHS)})\) has been evaluated in a rat model, showing good mechanical properties up to 5 months and good biocompatibility.\(^28\)

#### 2.4.2 Nonabsorbable grafts

Polyvinylidene fluoride (PVDF) was first investigated in Canada in the mid 1990s as an alternative suture material to PP in vascular surgery.\(^23\) It soon turned out to feature advantageous physio-chemical and handling characteristics, as well as superior biocompatibility compared with PP.\(^24\) The first animal studies of PVDF polymer as surgical mesh material was performed in Aachen, Germany in 2002.\(^25\)

Although approved as a surgical mesh implant in humans since 2003 \((\text{in Germany})\) recent studies further underscored the potentially favorable tissue reaction and biocompatibility of PVDF as mesh material for pelvic floor repair. In a comparative study, Gerullis et al\(^29\) looked at inflammatory infiltration, amount of macrophages and connective tissue reaction to investigate whether mesh material could be improved by the coating of meshes with autologous plasma. This was true for all tested materials, however, PVDF performed better than polypropylene \((\text{PP – tension-free vaginal tape [TVT]})\) or reinforced PP \((\text{UltraPro})\) not coated.

#### 2.4.3 Tissue engineering

Tissue engineering using autologous muscle-derived stem cells (MDSC) has been studied for the treatment of SUI with intrinsic sphincter deficiency, with the advantage of the absence of a potential immunologic reaction. However, no scaffold with MDSC has been studied for the treatment of urethral hy-permobility.\(^30\)

Coating of a sling with autologous plasma before implantation could be used to improve material
Platelet-rich plasma (PRP) contains concentrated growth factors and cytokines, which regulate tissue reconstruction and have been studied extensively among trauma patients. To date, however, there is no evidence to support or oppose its use in women who suffer from SUI due to pubo-urethral ligament damage. PRP is an easily produced and relatively inexpensive biologic material. It is produced directly from the patient’s blood and is, thus, superior to synthetic materials in terms of potential adverse effects such as that from foreign body reaction.

### 2.4.4 Summary

An inflammatory reaction has been observed both in animal and human studies after implantation of polypropylene mid-urethral slings. A negative impact on the metabolism of both collagen and elastin, favoring catabolic reactions, was also shown in the rhesus macaque. The immunologic reaction has been suggested from one small study in humans. No risk of uro-genital cancer was observed in a large nationwide cohort study. Degradation or surface modification of polypropylene can be induced by material surrounded by infection (biofilm). New materials have been studied (permanent/absorbable slings, tissue engineering), but more studies in humans are needed. It is noteworthy that some potentially alternative materials with favorable characteristics as compared to PP like PVDF are not currently globally available.

### 3 HOST-MESH INTERACTIONS, INFECTION, AND THE RISK OF SLING COMPLICATIONS INTRINSIC TO POLYPROPYLENE AS A MATERIAL

Numerous studies have identified microbial colonization and infection as an important cause of mesh complications with an incidence ranging from <1% to 68%.

The Center for Disease Control (CDC) in the United States has established criteria defining surgical site infection. They include the following signs and symptoms: purulent discharge, local pain, tenderness, swelling, redness, or heat. In the field of pelvic floor surgery, the International Urogynecological Association (IUGA) and the International Continence Society (ICS) published a classification of pelvic reconstructive mesh complications by category, time of onset since implantation and site. However, to date, there are no published guidelines on the systematic identification and management of infection specifically related to mesh in general or to polypropylene in particular.

It appears to be important to primarily distinguish between colonization and infection, the first defining the mere presence of bacteria, the latter defining an inflammatory response of the host to this presence of bacteria. Conventional culture techniques (often discriminating at a level of >10^3 CFU/mL) demonstrated the presence of bacteria in 80% of explanted mesh, including poly-microbial growth at low bacterial density (<103 CFU/mL) with the species Lactobacillus spp, Coagulase-negative Staphylococcus, Corynebacterium spp, Streptococcus agalactiae, Group B, C, D- and G-Streptococci, Propionibacterium spp, Staphylococcus aureus, Escherichia coli, Klebsiella spp, Bacteroides spp, Enterococcus spp, and Proteus mirabilis.

In another study, commensal and pathogenic bacteria were cultured from explanted mesh, constituted of polypropylene only, from the nonsterile vagina. Obviously, the presence of bacteria in the absence of an inflammatory response is more likely to constitute colonization and it has yet to be determined, whether colonization itself contributes to complications such as exposure.

The composition and structure of the mesh material itself may render it susceptible to colonization, bacterial replication, and infection but there is no study evaluating the particular interaction of polypropylene compared to other materials. Bacteria have the capacity to constitute a biofilm which is a structure of bacterial cells cultured in a self-produced polymeric matrix, adherent to an inert or living surface. Biofilm impairs the effectiveness of both host responses and antimicrobial treatment and facilitates additional biofilm formation. Finally, it interferes with the integration of the implant into the host tissue and therefore may result or contribute to other sequelae such as mesh exposure. Biofilm production may also influence the low sensitivity of standard culture techniques which has led, together with the strong limitations regarding anaerobic bacteria cultivation, to the development of cultivation-independent molecular methods based on 16S rRNA permitting whole-genome sequencing. The identification of the whole microbiome, which defines the whole genome of bacteria present may offer greater insight. However, the role of specific organisms implicated, and their clinical relevance may be difficult to determine.

With regard to the prevention of mesh infection, there is no evidence for the practice of bathing implants in an antibiotic solution, for repeated antiseptic washing or for change of gloves before mesh insertion. Contamination and colonization already happen at the time of implantation in 80% of cases. Some clinicians suggest screening and treatment of bacterial vaginosis,
trichomoniasis, and candidiasis although these organisms do not seem to be specifically implicated in mesh complications. The guidelines issued by the World Health Organization stipulate intraoperative surgical antibiotic prophylaxis administered 60 to 120 minutes before surgery.

4 | THE IMPORTANCE OF SURGICAL APPROACH, ANATOMY, AND TECHNIQUE

It is clear that even the best-engineered car is no guarantee for a safe trip. Likewise, in surgery, there are numerous factors that influence the performance and the result of a procedure apart from the device utilized, and the material implanted. The most important factor is probably the surgeon and their technique. This is all the more true in modern pelvic floor surgery, in particular, sling surgery, as the incisions are very small, there is no visualization of the path of the implant, the instruments used are potentially harmful to the surrounding organs, and the result is very much dependent on the surgeons’ intuition.

In contrast to the usual small instruments needed in vaginal surgery, the sling kits contain long trocars designed for blind passage through the pelvis. Hence, the most important instrument that ensures patients’ safety is the guiding index finger of the surgeon that has to substitute for the visual sense. This type of surgery is optimally safe and efficacious only when a fundamental understanding of pelvic anatomy is present.

In the 20-year history of the reported complications of the TVT and transobturator tape (TOT) slings, it is clear that no vascular structure in the pelvis has been left unharmed. Numerous other serious complications have been reported such as bladder and bowel perforations, large hematomas, abscess formation in various locations, and even deaths. As there are few comparator materials currently available, it is not clear whether PP mesh itself or other factors (ie, surgical technique, etc) are responsible for these complications. A study of 328 surgical reinterventions after tension-free slings reported poor surgical technique as the most frequent cause of problems (45%), followed by incorrect indication (38%). This disturbing result emphasizes the quotation of the German gynecologist Ernst Bumm (1858-1925) who said that surgery is handcraft, but indication is science.

In a retrospective critical contemplation of this recent surgical era in which PP materials in the form of commercially available kits have been widely utilized, it is possible to conclude that the fundamental requirements of responsible surgical practice have been often violated. Under the pressure of the industry and influenced by marketing strategies, many physicians who were not familiar with pelvic floor surgery rapidly increased their pelvic floor reconstruction practices and started to utilize commercially available POP and sling kits which were marketed as “easy to use”. In addition, in the early years after regulatory approval, there was a relative absence of critical scrutiny of the potential harm and late complications of these new techniques due to early success in many case series leading to further adoption by practitioners.

Some authors have suggested that the anatomic principles upon which the MUS is performed are somewhat flawed. As described by its originators, the MUS should be placed at the midurethra but this has been questioned as the optimal location. In a study of 102 consecutive female patients, Kociszewski et al criticized that this standard approach does not take into account individual urethral length. They found that tapes positioned at <70% and >50% of total urethral length sonographically measured from the bladder neck were more likely to be cured without complications than those with the tape positioned outside this range (P <.001).

The authors proposed a “one-third rule” whereby the distance of the distal end of the vaginal incision from the external urethral orifice should equal one-third of the sonographic urethral length.

Another important anatomic issue is a pain in the region of the inner thighs in patients after TOT. The obturator nerve that exits the obturator foramen cranially and laterally splits into three major branches that variably run downwards between the adductor muscles (mm. adductor longus and brevis, pectineus, gracilis). They contain the afferent sensory fibers of the inner thighs that are at risk of being affected by the trocar and/or the TOT sling. Several meta-analyses have demonstrated a significantly higher risk of thigh/groin pain with TOT in comparison with TVT. This applies particularly for the inside-out technique (3.1% TOT vs 15.7% TVT-O) where the trocar is directed more laterally in this critical area thus getting much closer to the nerve stem. This is why a “safety zone” in the upper medial aspect of the obturator foramen has been defined with respect to various anatomical studies. More serious complications in this area include myositis, fascitis, and abscess formation.

A potential solution to avoid these complications is the use of SIS (single incision slings) that are anchored in the obturator membrane, not perforating through the muscles. A meta-analysis of 154 relevant reports and five randomized controlled trials involving a total of 678 patients demonstrated a clear advantage of the (no longer commercially available) Ajust sling (BARD Inc) in
comparison to TOT and TVT (RR = 0.30; 95% CI (0.11-0.85); P < .05) with respect to groin/thigh pain. However, the results showed no significant difference in the objective and patient-reported cure rates in the treatment of SUI between Ajust and TVT-O/TOT (RR = 0.97; 95% CI (0.90-1.05), P > .05).

On the other hand, the vaginal injuries were reported twice as much in TOT (OR, 2.08; 95% CI, 0.89-4.95) in comparison with TVT. Also the vaginal extrusion rate was higher in the TOT group (OR, 1.51; 95% CI, 0.51-4.43). Notably, special care has to be taken in particular in patients with a concomitant cystocele and/or high vaginal fornices. This also applies for SIS procedures. With the increasing rate of elderly and obese patients, these risk factors become even more prevalent and must be recognized.

But beyond these patient factors, the surgeons' education and training with respect to anatomy, physiology, and technical skills remain the keystones of successful treatment. This is certainly a never-ending process as methods, devices, and concepts are frequently changing. Overall, there are “four rights” for good prolapse and continence surgery: only the right surgeon should place the right implant in the right patient using the right technique.

5 | RESEARCH QUESTIONS

Is the incidence of complications seen with polypropylene mesh greater than that seen with other procedures for the surgical repair of SUI and POP, or is this due to greater numbers of procedures being done overall, and/or a more complete accounting of complications in the literature and/or greater information sharing due to the internet and social media?

If there is a greater incidence of complications with polypropylene mesh, what is the cause? Is this due to the inherent properties of polypropylene mesh or other factors such as poor patient selection, improper surgical technique, host immunological or inherent wound healing issues, vaginal/pelvic anatomical limitations or some other as of yet undetermined factors? Furthermore, how can we independently study these factors (and others) in an unbiased way in the current highly charged medico-legal environment?

Is there an inherent, as of yet unidentified and unalterable problem with polypropylene mesh as a reconstructive tool in the female pelvis which results in a greater risk of complications in the pelvis? As compared to polypropylene mesh, is there a superior material with respect to efficacy, safety, compatibility, and durability for the repair of SUI and POP?

How can we assess for the presence of, and clinical relevance of toxicity or autoimmunity related to unaltered or partially degraded polypropylene mesh? What are the methods to explore the possibility of a cellular or humoral autoimmunity to polypropylene?

Is there something unique about the vaginal anatomy and physiology which predisposes surgical placement of polypropylene mesh to a greater risk of complications such as a narrower margin for error as compared to other transvaginal SUI or POP repair procedures?

Is there a safer but equally effective location for a polypropylene sling than at the mid urethra?

What do we want to know about mesh-host interaction?

- Definitions to describe and report infection-related mesh complications (including acute infection, abscess, colonization/contamination).
- The role of the microbiome and bacterial colonization of implanted mesh on complications (including exposure and chronic pain).
- Recommendations on the assessment of mesh complications and to diagnose the microbial contribution and guide treatment.
- Optimal laboratory techniques for the identification of biofilm and related organisms to guide antimicrobial treatment.
- Factors that may identify women at higher risk of infective complications to both guide choice of reconstructive surgery and triage the role of antibiotics and surgery in the management of mesh complications.

6 | CONCLUSION

The safety and utility of polypropylene mesh for pelvic reconstruction, including the treatment of stress urinary incontinence remains controversial. A relationship with carcinogenesis is unlikely however, potentially relevant interactions with surrounding tissues are still being investigated including those related to immunity, and infection (biofilm, microbiome, etc.) Certainly, surgical technique and patient selection are critical factors in optimizing patient outcomes. Finally, with ongoing scrutiny including studies regarding safety, efficacy, and tolerability, and the emergence of alternative absorbable and nonabsorbable materials as well as various tissue engineering techniques, it is unclear whether polypropylene mesh will remain a commonly used material for vaginal reconstruction.

ORCID

Eric Rovner http://orcid.org/0000-0003-3950-8752
Ralf Anding http://orcid.org/0000-0001-5020-3445
REFERENCES

1. Petros PE, Ulmsten UI. An integral theory and its method for the diagnosis and management of female urinary incontinence. *Scand J Urol Nephrol Suppl.* 1993;153:1-93.

2. Wang LC, Al Hussein Al, Awamleh B, et al. Trends in mesh use for pelvic organ prolapse repair from the medicare database. *Urology.* 2015;86(5):885-891.

3. Slopnick EA, Hijaz AK, N: guyen CT, et al. National surgical trends and perioperative outcomes of midurethral sling placement for stress urinary incontinence. *Urology.* 2017;99:57-61.

4. Nager C, Tulikangas P, Miller D, Rovner E, Goldman H. Position statement on mesh midurethral slings for stress urinary incontinence. *Female Pelvic Med Reconstr Surg.* 2014;20(3):123-125.

5. Ford AA, Rogerson L, Cody JD, Aluko P, Ogah JA. Midurethral sling operations for stress urinary incontinence in women. *Cochrane Database Syst Rev.* 2017;7:CD006375.

6. Milani AL, Damoiseaux A, Inthout J, Kluivers KB, Witgthen MJJ. Long term outcome of vaginal mesh or native tissue in recurrent prolapse: a randomized controlled trial. *Int. Urogynecol J.* 2018;29:847-858.

7. Liang R, Abramowitch S, Mani D, Nolfi AL, Liang R, Abramowitch SD, Moalli PA. Characterization of the host inflammatory response following implantation of prolapse mesh in rhesus macaque. *Am J Obstet Gynecol.* 2015;213(5):668.e1-668.e10.

8. Wolf MT, Dearth CL, Ranallo CA, et al. Macrophage polarization in response to ECM coated polypropylene mesh. *Biomaterials.* 2014;35(25):6838-6849.

9. Brown BN, Mani D, Nolfi AL, Liang R, Abramowitch SD, Moalli PA. Characterization of the host inflammatory response following implantation of prolapse mesh in rhesus macaque. *Am J Obstet Gynecol.* 2015;213(5):668.e1-668.e10.

10. Cohen Tervaert JW. Autoinflammatory/autoimmunity syndrome induced by adjuvants (Shoenfeld’s syndrome) in patients after apolipoprotein mesh implantation. *Best Pract Res Clin Rheumatol.* 2018;32(4):511-520.

11. Jakovlev VV, Guelcher SA, Bendavid R. Degradation of polypropylene in vivo: a microscopic analysis of meshes explanted from patients. *J Biomed Mater Res B Appl Biomater.* 2017;105(2):237-248.

12. Roman S, Mangir N, MacNeil S. Designing new synthetic materials for use in the pelvic floor: what is the problem with the existing polypropylene materials? *Curr Opin Urol.* 2019;29(4):407-413.

13. Nygaard I. Approval process for devices and mesh for surgical treatment of pelvic organ prolapse and urinary incontinence. *Clin Obstet Gynecol.* 2013;56(2):229-231.

14. Rovner E, Athanasou S, Choo M-S, et al. Surgery for urinary incontinence in women. In: Abrams P, Cardozo L, Wein AJ, eds. *Incontinence.* 6th ed., 2017.

15. Margules A, Greiman A, Rovner ES: Identifying factors responsible for mesh sling re-explorative surgery: the case for surgical technique. [Abstract]. SUFU Annual meeting Miami, FL, 2019.

16. Falconer C, Söderberg M, Blomgren B, Ulmsten U. Influence of different sling materials on connective tissue metabolism in stress urinary incontinent women. *Int Urogynecol J Pelvic Floor Dysfunct.* 2001;12(suppl 2):S19-S23.

17. de Almeida SH, Rodrigues MA, Gregório E, Crespígio J, Moreira HA. Influence of sling material on inflammation and collagen deposit in an animal model. *Int J Urol.* 2007;14(11):1040-1017.

18. Liang R, Zong W, Palcsey S, Abramowitch S, Moalli PA. Impact of prolapse meshes on the metabolism of vaginal extracellular matrix in rhesus macaque. *Am J Obstet Gynecol.* 2015;212(2):174.e1-174.e7.

19. Altman D, Rogers RG, Yin L, Tamussino K, Ye W, Iglesia CB. Cancer risk after midurethral sling surgery using polypropylene mesh. *Obstet Gynecol.* 2018;131(3):469-474.

20. Wang AC, Lee LY, Lin CT, Chen JR. A histologic and immunohistochemical analysis of defective vaginal healing after continence taping procedures: a prospective case-controlled pilot study. *Am J Obstet Gynecol.* 2004;191(6):1868-1874.

21. Clavé A, Yahi H, Hamou J-C, Montanari S, Gounon P, Clavé H. Polypropylene as a reinforcement in pelvic surgery is not inert: comparative analysis of 100 explants. *Int Urogynecol J.* 2010;21:261-270.

22. de Tayrac R, Oliva-Lauraire MC, Guiraud I, Henry L, Vert M, Mares P. Long-lasting biodegradable poly(lactic acid) (PLA94) mesh: a new approach for soft tissue reinforcement based on an experimental pilot study. *Int Urogynecol J Pelvic Floor Dysfunct.* 2007;18(9):1007-1014.

23. Urban E, King MW, Guidoin R, et al. Why make monofilament sutures out of polyvinylidene fluoride? *ASAO J.* 1994;40(2):145-156.

24. Mary C, Marois Y, King MW, et al. Comparison of the in vivo behavior of polyvinylidene fluoride and polypropylene sutures used in vascular surgery. *ASAO J.* 1998;44(3):199-206.

25. Klinge U, Klosterhalfen B, Ottinger AP, Junge K, Schumpelick V. PVDF as a new polymer for the construction of surgical meshes. *Biomaterials.* 2002;23(16):3487-3493.

26. de Tayrac R, Chentouf S, Garreau H, et al. In vitro degradation and in vivo biocompatibility of poly(lactic acid) mesh for soft tissue reinforcement in vaginal surgery. *J Biomed Mater Res B Appl Biomater.* 2008;85(2):529-536.

27. de Tayrac R, Letouzev Y, Garreau H, Guiraud I, Vert M, Mares P. Tissue healing during degradation of a long-lasting biodegradable gamma-ray-sterilised poly(lactic acid) mesh in the rat: a 12-month study. *Eur Surg Res.* 2010;44(2):102-110.

28. Chapin K, Khalifa A, Mbimba T, et al. In vivo biocompatibility and time-dependent changes in mechanical properties of woven collagen meshes: a comparison to xenograft and synthetic mid-urethral sling materials. *J Biomed Mater Res B Appl Biomater.* 2019;107(3):479-489.

29. Gerullis H, Klosterhalen B, Boros M, et al. IDEAL in meshes for prolapse, urinary incontinence, and hernia repair. *Surg Innov.* 2013;20(5):502-508.

30. Surcel C, Savu C, Chibelean C, Iordache A, Mirvald C, Sinescu I. Comparative analysis of different surgical procedures for female stress urinary incontinence. Is stem cell implantation the future? *Rom J Morphol Embryol.* 2012;53(1):151-154.

31. Nikolopoulos KI, Pergialiotis V, Perrea D, Doumouchtsis SK. Restoration of the pubourethral ligament with platelet rich plasma for the treatment of stress urinary incontinence. *Med Hypotheses.* 2016;90:29-31.

32. Deffieux X, Letouzev Y, Savary D, et al. Prevention of complications related to the use of prosthetic meshes in prolapse surgery: guidelines for clinical practice. *Eur J Obstet Gynecol Reprod Biol.* 2012;165(2):170-180.
33. de Tayrac R, Letouzey V. Basic science and clinical aspects of mesh infection in pelvic floor reconstructive surgery. *Int Urogynecol J*. 2011;22(7):775-780.

34. Bowler PG, Duerden BI, Armstrong DG. Wound microbiology and associated approaches to wound management. *Clin Microbiol Rev*. 2001;14(2):244-269.

35. Costerton JW, Stewart PS, Greenberg EP. Bacterial biofilms: a common cause of persistent infections. *Science*. 1999;284(5418):1318-1322.

36. Vollebregt A, Troelstra A, van der Vaart CH. Bacterial colonisation of collagen-coated polypropylene vaginal mesh: are additional intraoperative sterility procedures useful? *Int Urogynecol J Pelvic Floor Dysfunct*. 2009;20(11):1345-1351.

37. Tamussino K. Postoperative infection. *Clin Obstet Gynecol*. 2002;45(2):562-573.

38. Petri E, Niemeyer R, Martan A, Tunn R, Naumann G, Koelbl H. Reasons for and treatment of surgical complications with alloplastic slings. *Int Urogynecol J*. 2006;17(1):3-13.

39. Petros PE, Ulmsten UI. An integral theory of female urinary incontinence. Experimental and clinical considerations. *Acta Obstet Gynecol Scand Suppl*. 1990;153:7-31.

40. Kociszewski J, Rautenberg O, Kuszka A, Eberhard J, Hilgers R, Viereck V. Can we place tension-free vaginal tape where it should be? The one-third rule. *Ultrasound Obstet Gynecol*. 2012;39:210-214.

41. Latthe P, Foon R, Tooze-Hobson P. Transobturator and retropubic tape procedures in stress urinary incontinence: a systematic review and meta-analysis of effectiveness and complications. *BJOG*. 2007;114:522-531.

42. Zhang P, Fan B, Zhang P, et al. Meta-analysis of female stress urinary incontinence treatments with adjustable single-incision mini-slings and transobturator tension-free vaginal tape surgeries. *BMC Urol*. 2015;15:64.

**How to cite this article:** Rovner E, de Tayrac R, Kirschner-Hermanns R, Veit-Rubin N, Anding R. Is polypropylene mesh material fundamentally safe for use as a reconstructive material in vaginal surgery: ICI-RS 2019? *Neurourology and Urodynamics*. 2020;39:S132–S139. https://doi.org/10.1002/nau.24312