Archives of Gynecology and Obstetrics (2019) 299:1337–1343
https://doi.org/10.1007/s00404-019-05117-9

GENERAL GYNECOLOGY

Laparoscopic pectopexy: a follow-up cyclic biomechanical analysis determining time to functional stability

A. Sauerwald[1] · L. Langer[2,3] · D. Ratiu[3] · A. Prescher[4] · M. Scaal[5] · G. K. Noé[6] · K. Wegmann[7] · D. R. Bulian[8] · C. Eichler[3,9]

Received: 12 September 2018 / Accepted: 8 March 2019 / Published online: 23 March 2019

Abstract

Introduction Pectopexy, a laparoscopic method for prolapse surgery, showed promising results in previous transient testing by this group. It was shown that a single suture, yielding an ultimate load of 35 N, was equivalent to continuous suturing. This was demonstrated in an in vitro cadaver study. This transient data were used to establish an elastic stress–strain envelope. It was now possible to proceed to dynamic in vitro analysis of this surgical method to establish time to functional stability.

Methods Cyclic testing of this fixation method was performed on human female embalmed cadaver (cohort 1) and fresh, non-embalmed cadaver (cohort 2) pelvises. The testing envelope was 5–25 N at a speed of 1 mm/s. 100 load regulated cycles were applied.

Results 100 cycles were completed with each model; no overall system failure occurred. Steady state, i.e., functional stability was reached after 14.5 (± 2.9) cycles for the embalmed group and after 19.1 (± 7.2) cycles for the non-embalmed group. This difference was statistically significant $p = 0.00025$.

Conclusion This trial showed in an in vitro cyclic testing of the pectopexy method that functional stability may be achieved after no more than 19.1 cycles of load exposure. When remaining within the established load envelope of below 25 N, patients do not need to fear global fixation failure. Testing did demonstrate differences in non-embalmed and embalmed cadaver testing. Embalmed cadaver testing tends to underestimate time to steady state by 26.3%.

Keywords Pectopexy · Laparoscopic · Dynamic · In vitro · Analysis · Cyclic testing · Biomechanical · Biomechanic

Introduction

As discussed in our previous publication a new laparoscopic method for prolapse surgery, designed for obese women, called pectopexy, was presented by Banerjee and

A. Sauerwald, L. Langer and C. Eichler contributed equally to this work.

D. Ratiu, A. Prescher, M. Scaal, G. K. Noé, K. Wegmann and D. R. Bulian also contributed equally to this work.

✉ C. Eichler
ceichler@gmail.com; christian.eichler@uk-koeln.de

1 Department of Gynecology and Obstetrics, St. Marien-Hospital, Düren, Germany

2 Breast Cancer Center, Municipal Hospital Holweide, Cologne, Germany

3 Department of Obstetrics and Gynecology, Faculty of Medicine and University Hospital Cologne, University of Cologne, Cologne, Germany

4 Department of Anatomy, RWTH Aachen University, Aachen, Germany

5 Department of Anatomy, University of Cologne, Cologne, Germany

6 Department of Gynecology and Obstetrics, Hospital Rhein-Kreis-Neuss, Faculty University of Witten/Herdecke, Witten, Germany

7 Center for Orthopedic and Trauma Surgery, University Medical Center, Cologne, Germany

8 Department of Abdominal, Vascular and Transplant Surgery Cologne-Merheim Medical Center (CMMC), Witten/Herdecke University, Witten, Germany

9 Brustzentrum der Universitätsfrauenklinik Köln, Kerpener Straße 34, 50931 Cologne, Germany

Noe [1]. Although sacrocolpopexy is still the gold standard in prolapse surgery, robot-assisted sacrocolpopexy as well as pectopexy play an ever-increasing role. Pectopexy uses the pectineal ligament for a tension-free mesh suspension and has by now been established by several work groups [2–7]. A detailed discussion of the value of this method is given in the previous analysis as well as recent literature [8–10]. Recent in vivo trials show no evidence of recurrent prolapse and or constipation with this new method. Postoperative de novo stress urinary incontinence and de novo urgency incontinence were low (below 5%) while female sexual function and prolapse-related quality of life, as determined by questionnaire, improved significantly ($p < 0.05$) [10]. Given the potential of this new method, we initially investigated the ultimate load yielded as a function of suturing technique [11] in an attempt to reduce surgical time by minimizing laparoscopic suturing. The initial question whether multiple or single sutures were required was answered. Ultimate loads of 35 N were achieved with single sutures. No statistically significant difference could be shown in comparison to multiple or continuous suturing. Also, displacement at failure did not differ between these groups. Hence, the in vitro evaluations of this method showed that continuous suturing or the implementation of multiple sutures is not necessary in a laparoscopic mesh/pectineal ligament fixation (pectopexy). Through all previous testing the surgical mesh remained the limiting factor. Having established a solid transient stress–strain analysis for this in vitro scenario, dynamic, i.e., cyclic testing now became possible. An elastic region, a region within the stress–strain diagram where no permanent damage is done to the fixation method, was extrapolated from the stress–strain diagrams of the previous trials. This is elastic region is the basis of this study.

As commonly done in orthopedic surgery, one wishes to establish a form of functional stability before patients leave the hospital. This has not at all been evaluated in an in vitro model for any type of prolapse surgery. Since no such data are available at this point our clinical team, having performed more than 1000 pectopexies, generally recommends a prolonged period of rest. This study, therefore, aims to establish at what point final stability is achieved in pectopexy in an in vitro cadaver approximation of the in vivo scenario. The authors are aware of the fact that wound healing and mesh ingrowth cannot be evaluated by this method. This trial evaluates immediate post-surgical stability only. To do so, dynamic, i.e., cyclic mechanical testing was performed. The methodology was adopted from trauma and orthopedic surgery research where it is often used to evaluate initial stability of osteosyntheses or ligament fixation techniques [12, 13]. This study thus asked the following questions:

1. Did the transient testing from our previous trial establish an accurate elastic stress–strain diagram which allows for non-destructive cyclic testing?
2. Is the assumed testing envelope 5–25 N (< 35 N) accurate in depicting the elastic region of the pectopexy method? Hypothesis: 0 overall failures
3. Using this testing envelope: how many cycles are necessary until functional stability is achieved?
4. Based on the results of the cyclic analysis, which post-surgical intervention might be needed to reduce intra-abdominal pressure (i.e., catheter, laxative treatment, etc.)?
5. Is it necessary to perform this type of testing on a human non-embalmed, fresh cadaver pelvises or may embalmed cadavers be used.

Methods

Cyclic testing of the fixation method was performed on human-embalmed cadavers (cohort 1) and fresh, non-embalmed cadaver pelvises (cohort 2). Preparation of the pectineal ligament was performed by an experienced surgeon. $N = 20$ embalmed cadaver-pelvis half sections were harvested form 16 embalmed female cadavers. The remaining pelvises did not display sufficient pectineal ligaments. The average cadaver age was 83.3 years. All cadavers were procured from the Center of Anatomy at the University of Cologne. The second cohort of fresh, non-embalmed pelvises was procured from the Institute of Anatomy at the University of Aachen. $N = 10$ non-embalmed, fresh cadaver pelvis half sections were harvested form five cadavers. The average age was 88.6 years. Age did not differ significantly between these cohorts. All pelvises were female. Identifying patient data was available only to coauthors P.A. and S.M..

A total of 30 trials were performed. All human specimens were previously untested. Human cadaver recruitment was de novo. An undyed, monofilament, partially absorbable mesh was used: SERA MESH® PA (15 × 5 mm—SERAG-WIESSNER GmbH & Co. KG, Naila, Germany). A synthetic, braided, non-absorbable Ethibond® suture 0, FSLX needle, 75 cm green filament (Ethicon/Johnson & Johnson, Somerville, NJ, USA) was used in all cohorts. Analysis was performed on an Instron 5565® test frame using the Bluehill 2 Software®. All tests were cyclic, i.e., dynamic tests. A required preload of 2 N was applied. Thereafter cyclic testing was performed and a 5–25 N testing envelope was chosen as previous transient testing had concluded a maximum load of 35 ± 12 N [11]. Testing took place at a speed of 1 mm/s. 100 cycles were applied.

Procedure

Fresh cadaver pelvises (non-embalmed) were prepared in a manner allowing the pectineal ligament to be placed in the Instron 5565® test frame appropriately, while still attached to the surrounding bone structure. Non-embalmed cadavers were unfrozen only once. Testing proceeded in a cyclic/dynamic manner as previously established [12, 14–17]. Embalmed cadavers were prepared the same manner, although unfreezing was not necessary. Figure 1 shows the testing set up. Pelvis fixation to the test frame was rigid via a metal bar. The load exposure vector was equal to the previous work and similar to an in vivo scenario. 100 cycles were chosen as relevant changes were expected to occur within the timeframe. Also, exceeding this number of cycles will result in increasing cadaver deterioration which in turn will influence the overall mechanical properties. Since steady state was reached early on, longer testing was not needed.

Graphical analysis

This type of testing is a lengthy process. Preparation of human tissue as well as implementing the in vitro pectopexy is a complex matter and is described in the original work by Noe et al. Furthermore, cyclic testing is time-consuming and presents unique challenges in the analysis of the data. Data sets of well above 10,000 data points are very common depending on analysis increment. Our analyses yielded displacement data as a function of changing load. Subsequent programmed automated analysis filtered out single maxima and minima displacement endpoints as a dependent variable of applied load. This in turn enabled graphic analysis of maxima and minima displacement curves. Initially, these types of curves tend to increase steeply and nonlinearly. Once a steady state is reached, however, a linear progression is seen. This behavior is unique to the analysis of complex structures such as osteosyntheses in combination with bone structure [12, 13] and/or ligament-suture-mesh compositions [12]. As the slope of the displacement maxima (as a function of testing cycle) approaches zero and the same is seen for the minima (as a function of testing cycle) a steady state is reached. Slope values should not differ significantly from one another. The ratio between the slopes should be approaching 1. As the change from non-linearity to linearity occurs, an approximation of cycles to steady state becomes possible. As a side note: when testing a rigid material within its elastic region this type of behavior is generally not seen. Also, the authors are aware of the limitation of this type

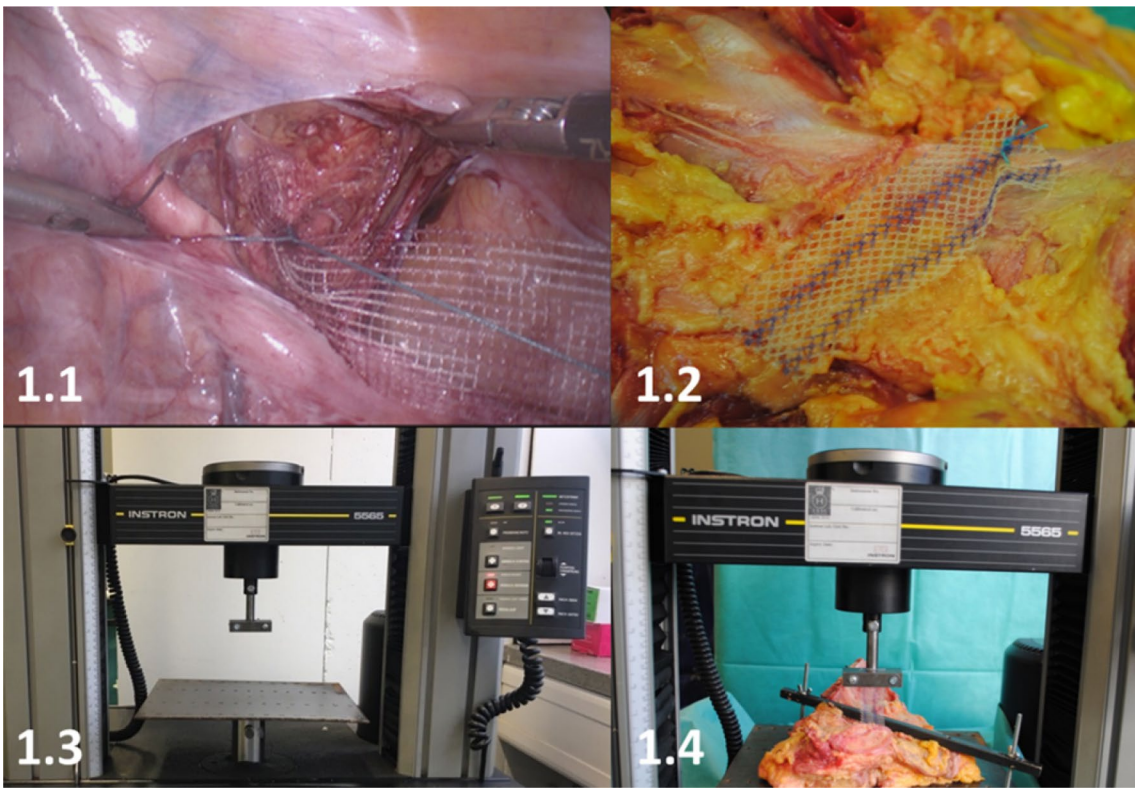

Fig. 1 Shown are four images of both the in vivo and in vitro pectopexy. **1.1** A single suture and mesh composition in vivo during a laparoscopic pectopexy. **1.2** A single suture and mesh composition in the in vitro model. **1.3** The Instron testing set up. **1.4** The complete testing set during dynamic testing

of analysis as a true steady state can never be reached, i.e., final slope of zero. The final stabilization of any such surgical method is reached through wound healing and mesh ingrowth.

Statistics

Statistical analysis was performed using the VassarStats® (Vassar College, Poughkeepsie, NY, USA) statistics program. *T* tests were used to evaluate significances when appropriate.

Ethics committee approval

Informed consent was provided for all cadavers involved in this study. This study was conducted in accordance with institutional review board standard operating procedures. Human cadaver testing was performed on cadavers which were donated to medical research for this explicit purpose only. An ethics committee vote was initiated, but deemed unnecessary by the "Ethikkommission der Aerztekammer Nordrhein".

Embalmed ligaments

There are several different methods available for cadaver fixation such as the use of alcohols and aldehydes. This trial used a 4–8% (by volume) formaldehyde solution as commonly used in anatomical studies. No biomechanical data are available on the properties of ligaments exposed to different methods of fixation. As this trial addresses the issue of formaldehyde embalmed ligaments versus non-embalmed ligaments, subsequent trials will also have to address the issue of different embalming methods.

Results

A total of 30 trials was conducted and divided in two cohorts. Cohort 1 consisted of 20 embalmed pelvis half sections allowing for 20 ligaments to be tested. Cohort 2 contained 10 non-embalmed, fresh cadaver pelvis half sections allowing for 10 ligaments to be tested. We applied the hypothesis that 100 cycles of dynamic testing could be performed due to the fact that this testing took place within the elastic region of the previously established stress–strain diagram [11]. It was shown that both cohorts yielded complete test runs only. 100 cycles were completed within each model and steady state was reached in all cases. Table 1 shows the overall results. Steady state was reached after 14.5 (±2.9) cycles for the embalmed group and after 19.1 (±7.2) cycles for the non-embalmed group. The difference is statistically significant $p = 0.00025$. This indicates a stiffer and more rigid ligament entity within the embalmed cohort. Steady state was determined by graphical analysis; the numerical results are shown in Table 2. When reaching steady state, cohort 1 resulted in a linear maximum displacement slope of 0.022 (±0.009) mm/cycle and a linear minimum displacement slope of 0.025 (±0.006) mm/cycle. Slopes did not differ significantly, i.e., steady state was reached $p = 0.569$.

Cohort 2, testing non-embalmed cadaver ligaments, resulted in a linear maximum displacement slope of 0.025 (±0.006) mm/cycle and a linear minimum displacement slope of 0.027 (±0.006) mm/cycle. Slopes did not differ significantly either with a $p = 0.262$.

Table 1 This table shows the overall results of two cohorts

Evaluated entity Total trials = 30	Number tested *n*	Testing envelope *N*	Preload *N*	Age (average) Years	Steady state reached Cycle	Failures/ cycles completed
Cohort 1 (embalmed)	20	5–25	2	83.3	14.5 (±2.9)	None/100
Cohort 2 (non-embalmed)	10	5–25	2	88.6	19.1 (±7.2)	None/100
p value				0.098	0.00025	

All dynamic testing was completed; no global failures occurred; steady state was reached in all cases

Table 2 This table shows the overall results of the graphic analysis

Evaluated entity Total trials = 30	Number tested *n*	Steady state slope maxima mm/cycle	Steady state slope minima mm/cycle	*p* value	Ratio
Cohort 1 (embalmed)	20	0.022 (±0.009)	0.025 (±0.006)	0.569	0,87
Cohort 2 (non-embalmed)	10	0.025 (±0.006)	0.027 (±0.006)	0.262	0.94

Maxima and minima displacements versus cycle slopes reached a steady state for both cases. Slopes do not differ significantly

There were no recorded global failures. There was no ligament failure, no mesh failure, and no suture failure. Testing was successfully performed within the elastic envelope established in the previous trial.

Discussion

This is the first dynamic biomechanical analysis in this area. It is also the first dynamic analysis of the pectopexy surgical procedure. There is no comparable data available.

Except for the effects of wound healing, we may deduce several other clinically relevant facts with the application of dynamic testing. Since steady state could be reached in all cases, we were able to estimate time to immediate functional stability for this type of fixation method. This may allow for an improvement of overall clinical protocol.

Steady state

This analysis used a graphic method to quantify cycles to steady state for this biosynthetic fixation (ligament-suture-mesh) scenario. Load-dependent cyclic testing resulted in more than 10,000 data points, recording displacement as a function of changing load (from 5 to 25 N). These data sets were filtered in manner leaving displacement maxima and minima as a function of cycle. Both curves initially display a non-linear patterns; during this time the ligament-suture-mesh combination "settles in". This phenomenon is commonly observed in orthopedic osteosyntheses dynamic testing scenarios. When testing a single rigid material this "settling in" effect is not seen. After the initial non-linear portion, i.e., after as functional stability is reached, maximum and minimum displacement curves become linear and slopes do not differ significantly any more.

This was the case in both cohorts where cohort 1 (embalmed cadavers) resulted in a linear maximum displacement slope of 0.022 mm/cycle and a linear minimum displacement slope of 0.025 mm/cycle. No statistical difference can be seen $p = 0.569$. A trend towards increasing stability can be reported as the slope of the minimum displacement is numerically greater than that of the maximum displacement. This means that global displacement per cycle may decrease very slightly over time. This effect is, however, compensated and consolidated by wound healing. The same is true for the non-embalmed cohort 2 where a linear maxima displacement slope of 0.025 mm/cycle and a linear minima displacement slope of 0.027 mm/cycle were shown. They did not differ significantly $p = 0.262$. Numerically, slopes converge decreasing global displacement. Again, this effect will eventually be compensated by wound healing.

Furthermore, our previous work showed a maximum load of approximately 35 N limiting the elastic envelope to values below that. We chose 5 –25 N although other groups, such as Zimkowski et al. reported surgical polyester mesh (PETKM14001, Textile Development Associates) failure at 16.65 ± 3.30 N in a semi-physiological setting [18, 19]. Dynamic analysis, therefore, had to prove that our established testing envelope was in fact correct. Since 100 cycles were completed for all trials and no global failure occurred functional stability was reached in all cases and our testing envelope was proven correct.

Cycles until steady state

Steady state is reached after non-linear progression of the maximum/minimum displacement versus cycles graph reaches its linear portion. This was the case after 14.5 cycles (± 2.9) in the embalmed group (cohort 1) and after 19.1 (± 7.2) cycles for the non-embalmed group (cohort 2). The difference was statistically significant $p = 0.00025$. A reason for this difference may be the more rigid nature of the ligament after the embalming process as all other parameters were not changed between the two cohorts. A subsequent section will address this issue. Overall a maximum of 19.1 cycles are needed to achieve steady state with the embalmed group reaching this goal five cycles earlier. From a clinical point of view, this type of information is very important. It is the opinion of these authors that 19 cycles of 25 N will be reached within the first 2 days of post-surgical hospitalization. Intra-abdominal pressure due to repositioning of the patient after surgery, coughing, bowel movement, etc., places this number of cycles easily within the first 2 days of post-surgical hospitalization. This observation also correlates with clinical experiences of these authors in well over 1000 pectopexy patients. We, therefore, conclude that no extended measures are needed beyond 48 h to prevent ligament-suture-mesh failure. Stability is shown to occur very early.

Embalmed ligaments versus non-embalmed ligaments

The main problem evaluating novel surgical methods in an in vitro cadaver scenario is achieving a close approximation of the in vivo situation. Several publications are available estimating the value of embalmed cadaver testing for the approximation of non-embalmed fresh human tissue [20]. Unfortunately, the difference in tissue stiffness influences the number of cycles needed to achieve steady state. We demonstrated that embalmed cadaver testing underestimates time to steady state by 26.3%. This in turn brings up the question whether embalmed cadaver testing on ligaments represents an adequate in vivo approximation. It is the opinion of this group that this is the case. However, one must expect the embalmed cadaver ligaments to be more rigid,

skewing results in that direction. Since fresh, non-embalmed specimens are difficult and expensive and difficult to procure, our data may also be used to extrapolate results from embalmed cadaver trials.

Overall the following questions could be answered:

1. Did the transient testing from our previous trial establish an accurate elastic stress–strain diagram which allows for non-destructive cyclic testing? Yes, Sauerwald et al. [11] very adequately established an elastic region.
2. Is the assumed testing envelope 5–25 N (< 35 N) accurate in depicting the elastic region of the pectopexy method? Hypothesis: 0 overall failures. Neither cohort (embalmed and non-embalmed) showed global failures. Cyclic testing was completed, and steady state was reached in all cases.
3. Using this testing envelope: how many cycles are necessary until functional stability is achieved? Steady state was reached after 14.5 cycles for the embalmed group and after 19.1 cycles for the non-embalmed group.
4. Based on the results of the cyclic analysis, which post-surgical interventions might be needed to reduce intra-abdominal pressure? Steady state is reached quickly. We estimate that no more than 2 days of hospitalization are needed.
5. Is it necessary to perform this type of testing on a human non-embalmed, fresh cadaver pelvises or may embalmed cadavers be used? Unfortunately, results differ when using embalmed and non-embalmed ligaments. Embalmed cadavers may be used. However, results must be extrapolated accordingly.

Further investigation

Naturally, these results apply only the testing scenario established here. Different suturing methods, different meshes as well as a different testing envelopes and testing speeds would alter cycles to steady state. Future testing might also directly compare different suspension methods in a head to head manner. In addition, the next series of evaluations in this area will have to examine whether failure at the cervical fixation point impacts overall outcome. Clinical experience shows that this may have an impact, although these types of failures were only observed after laparoscopic subtotal hysterectomy procedures due to local cervical necrosis.

Conclusion

This trial showed in an in vitro approximation with cyclic testing of the pectopexy surgical method that functional stability may be achieved after approximately 19 cycles of load exposition. When remaining within the established load envelope of below 25 N, patients do not need to fear global fixation failure. Testing did demonstrate differences in non-embalmed and embalmed cadaver testing, showing embalmed cadaver testing to underestimates time to steady state by 26.3%.

Author contributions AS: project development and manuscript writing. LL: project development, data collection, and manuscript writing. DR: manuscript writing/editing. AP: data collection. MS: data collection. GKN: project development manuscript writing/editing. KW: data collection. DRB: manuscript writing/editing. CE: project development, data collection, and manuscript writing.

Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

References

1. Banerjee C, Noe KG (2011) Laparoscopic pectopexy: a new technique of prolapse surgery for obese patients. Arch Gynecol Obstet 284:631–635
2. Alkatout I, Mettler L, Peters G, Noe G, Holthaus B, Jonat W et al (2014) Laparoscopic hysterectomy and prolapse: a multiprocedural concept. JSLS 18:89–101
3. Huber SA, Northington GM, Karp DR (2014) Bowel and bladder dysfunction following surgery within the presacral space: an overview of neuroanatomy, function, and dysfunction. Int Urogynecol J 26:941–946
4. Lee RK, Mottrie A, Payne CK, Waltregny D (2014) A review of the current status of laparoscopic and robot-assisted sacrocolpopexy for pelvic organ prolapse. Eur Urol 65:1128–1137
5. Maher C, Baessler K, Glazener CM, Adams EJ, Hagen S (2004) Surgical management of pelvic organ prolapse in women. Cochrane Database Syst Rev 4:CD004014
6. Nygaard IE, McCreery R, Brubaker L, Connolly A, Cundiff G, Weber AM et al (2004) Abdominal sacrocolpopexy: a comprehensive review. Obstet Gynecol 104:805–823
7. Siddiqui NY, Grimes CL, Casiano ER, Abed HT, Jeppson PC, Olivera CK et al (2015) Mesh sacrocolpopexy compared with native tissue vaginal repair: a systematic review and meta-analysis. Obstet Gynecol 125:44–55
8. Tahaoglu AE, Bakir MS, Peker N, Bagli I, Tayyar AT (2018) Modified laparoscopic pectopexy: short-term follow-up and its effects on sexual function and quality of life. Int Urogynecol J 29:1155–1160
9. Cezarino BN (2017) Editorial comment: laparoscopic pectopexy: initial experience of single center with a new technique for apical prolapse surgery. Int Braz J Urol 43:910
10. Kale A, Biler A, Terzi H, Usta T, Kale E (2017) Laparoscopic pectopexy: initial experience of single center with a new technique for apical prolapse surgery. Int Braz J Urol 43:903–909
11. Sauerwald A, Niggl M, Puppe J, Prescher A, Scaal M, Noe GK et al (2016) Laparoscopic pectopexy: a biomechanical analysis. PLoS ONE 11:e0144143
12. Thelen S, Schneppendahl J, Baumgartner R, Eichler C, Koebke J, Betsch M et al (2013) Cyclic long-term loading of a bilateral

fixed-angle plate in comparison with tension band wiring with K-wires or cannulated screws in transverse patella fractures. Knee Surg Sports Traumatol Arthrosc 21:311–317
13. Hackl M, Wegmann K, Ries C, Lappen S, Scaal M, Muller LP (2017) Annular ligament reconstruction with the superficial head of the brachialis: surgical technique and biomechanical evaluation. Surg Radiol Anat 39:585–591
14. Thelen S, Betsch M, Schneppendahl J, Grassmann J, Hakimi M, Eichler C et al (2013) Fixation of multifragmentary patella fractures using a bilateral fixed-angle plate. Orthopedics 36:e1437–e1443
15. Thelen S, Schneppendahl J, Jopen E, Eichler C, Koebke J, Schonau E et al (2012) Biomechanical cadaver testing of a fixed-angle plate in comparison to tension wiring and screw fixation in transverse patella fractures. Injury 43:1290–1295
16. Wild M, Eichler C, Thelen S, Jungbluth P, Windolf J, Hakimi M (2010) Fixed-angle plate osteosynthesis of the patella—an alternative to tension wiring? Clin Biomech (Bristol, Avon) 25:341–347
17. Wild M, Thelen S, Jungbluth P, Betsch M, Miersch D, Windolf J et al (2011) Fixed-angle plates in patella fractures - a pilot cadaver study. Eur J Med Res 16:41–46
18. Zimkowski MM, Rentschler ME, Schoen J, Rech BA, Mandava N, Shandas R (2013) Integrating a novel shape memory polymer into surgical meshes decreases placement time in laparoscopic surgery: an in vitro and acute in vivo study. J Biomed Mater Res A 101:2613–2620
19. Zimkowski MM, Rentschler ME, Schoen JA, Mandava N, Shandas R (2014) Biocompatibility and tissue integration of a novel shape memory surgical mesh for ventral hernia: in vivo animal studies. J Biomed Mater Res B Appl Biomater 102:1093–1100
20. Eichler C, Schell J, Uener J, Prescher A, Scaal M, Puppe J et al (2016) Inframammary fold reconstruction: a biomechanical analysis. Plast Reconstr Surg Glob Open 4:e634