



Comparison of mesh fixation devices for laparoscopic ventral hernia repair: an experimental study on human anatomic specimens

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Abstract

Background As there is a lack of clarity in terms of the tensile strength of mesh fixation for laparoscopic ventral hernia repair (LVHR), our aim was to investigate the immediate tensile strength of currently available mesh fixation devices on human anatomic specimens.

Methods Sixteen recently deceased body donators (mean body mass index of 24.4 kg/m²) were used to test the immediate tensile strength (Newton) of 11 different LVHR mesh fixation devices.

Results Each of the 11 different laparoscopic fixation devices was tested 44 times. Non-articulating tackers provided higher fixation resistance to tensile stress in comparison to articulating tackers (5.1-mm ReliaTack™: 16.9 ± 8.7 N vs. 12.2 ± 5.6 N, $p=0.013$; 7-mm ReliaTack™: 19.8 ± 9.4 N vs. 15.0 ± 7.0 N, $p=0.007$). Absorbable tacks with a greater length, i.e. ≥ 6 mm (7-mm ReliaTack™, 6-mm SorbaFix™ and 7.2-mm SecureStrap™) had significantly higher fixation tensile strength than tacks with a shorter length, i.e. < 6 mm (5.1-mm ReliaTack™ and 5.1-mm AbsorbaTack™) ($p < 0.001$). Furthermore, transfascial sutures (PDS 2-0 sutures 26.3 ± 5.6 N) provided superior fixation tensile strength than 5.1-mm AbsorbaTack™ (13.6 ± 7.3 N) and cyanoacrylate glues such as LiquiBand FIX8™ (3.5 ± 2.4 N) ($p < 0.001$, respectively). There was a significant deterioration in fixation capacity in obese body donators with a body mass index > 30 kg/m² (13.8 ± 8.0 vs. 17.9 ± 9.7 N, $p=0.044$).

Conclusions Although articulating laparoscopic tackers improve accessibility and facilitate the utilization of tacks within the fixation weak spot adjacent to the trocar placement, an articulating shaft that is not ergonomic to use may limit mechanisms of force transmission. For mesh fixation in LVHR, transfascial sutures and tacks with a longer length provide better immediate fixation tensile strength results.

Keywords Laparoscopic ventral hernia repair · Mesh fixation · Articulating fixation device · Absorbable tacks · Fixation tensile strength

For laparoscopic ventral hernia repair (LVHR), tension-free surgical treatment using a permanent mesh to reinforce abdominal wall defects has widely been recommended [1,

2]. A variety of synthetic meshes and fixation devices have been used in practice, but there is currently no clear conclusion as to the best choice of mesh and fixation materials. Only procedures involving sufficient mesh overlapping, i.e. > 5 cm of overlap increase the rate of a recurrence-free outcome [1, 2]. Laparoscopic mesh fixation devices play a crucial role in relation to both surgical effectiveness and postoperative complications [3]. Particularly with the development of high-quality mesh construction, mesh slippage or migration resulting from insufficient fixation is an avoidable source of recurrence following surgery.

Traditional transfascial sutures or non-absorbable titanium tacks used for securing mesh provide strong fixation tensile strength, but these materials may result in pain

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syndrome, adhesion formation or fistulas [4–6]. For this reason, absorbable tacks have become popular in the field of laparoscopic hernia repair. These absorbable mesh fixation devices minimize the adverse effects of foreign body reactions in the abdomen and have similar postoperative pain rates, but they have been reported to be associated with higher hernia recurrence rates [7, 8].

In the standard LVHR procedure, all three trocars are positioned in the far-lateral area and on one side of the abdominal wall. With conventional rigid laparoscopic instruments, a weak spot in the placement of mesh fixation often arises at the mesh border adjacent to the trocar. Additionally, by accessing the mesh area using a lateral approach, there is a risk for mesh shift during tacking [9]. Overall, the required perpendicular tack placement angle into the mesh may not be achieved, precipitating fixation line failure [3, 10, 11]. New inventions including articulating laparoscopic instruments have promised to improve accessibility and to facilitate the use of tacks at an ideal tack entry angle [11, 12]. Nonetheless, such articulating laparoscopic equipment may lose application force in the articulating shaft, resulting in reduced tack penetration depths and therefore diminished fixation retention strength.

Consequential to the lack of clarity in laparoscopic mesh fixation, we aimed to investigate the immediate tensile strength of common mesh fixation devices available in LVHR using an experimental study on human anatomic specimens. The effects of articulating instruments, tack length, fixation materials and overweight abdomen on the fixation tensile strength are emphasized in this paper.

Materials and methods

This experimental study using non-embalmed human anatomic specimens received institutional review board approval (1778/2016 Ethics Committee of the Medical University of Vienna). It included 16 recently deceased body donors with a mean age of $76.4 \pm \text{SD } 10.8$ years and mean body mass index BMI of $24.4 \pm \text{SD } 4.1 \text{ kg/m}^2$ (10 body donors in BMI category of 18.5–24.9 kg/m^2 , 4 body donors in BMI category of 25–29.9 kg/m^2 and 2 body donors in BMI category of $\geq 30 \text{ kg/m}^2$). All of them had voluntarily donated their bodies by their last will to the Center of Anatomy and Cell Biology of the Medical University of Vienna. The aim of this study was to test the immediate tensile strength of 11 different laparoscopic ventral hernia fixation devices (Table 1).

First, under clean but not sterile conditions, a midline laparotomy was performed and three trocars were laterally positioned. A 2 cm by 5 cm monofilament polyester mesh, coated with a bio-absorbable collagen film (Symbotex™ composite mesh, Medtronic, Dublin), was placed

intraperitoneally in the upper, middle (above and below arcuate line) and lower abdomen along the paramedian line. The distance between the mesh and the laterally placed trocar measured approximately 4 cm, similarly to the scenario of the above-mentioned mesh fixation weak spot. It was then fixed with one of the laparoscopic fixation devices. In the case of an articulating fixation instrument, the shaft was angled at 65° to place the tacks (Fig. 1).

Regarding the measurement of the fixation tensile strength, the mesh anchored via fixation materials was secured into a universal force measurement machine (advanced digital force gauges series 5, Mark-10 Corp., New York). The standardized pulling test was performed until the fixation materials became detached from the abdomen wall or the mesh itself ruptured. All tests were conducted immediately after mesh implantation, and the fixation tensile strength was measured in newtons (N). There were five cases of test invalidity due to improper mounting of the mesh into the force measurement machine and these were excluded from the results.

IBM-SPSS Version 20 (IBM Corp., New York) was used to handle the statistical analysis. Data were expressed as percentages for categorical variables and as the mean \pm standard deviation (SD) for continuous variables. Comparisons between the groups were performed utilizing Student's *t* test and one-way ANOVA as appropriate. All statistical tests were two-sided. A *p* value of <0.05 was considered to be statistically significant.

Results

A total of 484 valid measurement results were obtained in this experimental study using non-embalmed human anatomic specimens. Each of the 11 different laparoscopic fixation devices was tested 44 times. Overall results are illustrated in Fig. 2. With regard to the effects of flexibility in mesh fixation instruments, non-articulating application provided significantly higher resistance to tensile stress over articulating application. This was observed in two independent test series using 5.1-mm and 7-mm absorbable screw-like ReliaTack™ (group 1 vs. group 2, group 3 vs. group 4, Fig. 3).

In non-articulating instruments, absorbable fasteners with a greater length, i.e. ≥ 6 mm (ReliaTack™ 7 mm, SorbaFix™ 6 mm and SecureStrap™ 7.2 mm) had significantly higher fixation tensile strength than fasteners with a shorter length, i.e. < 6 mm (ReliaTack™ 5.1 mm and AbsorbaTack™ 5.1 mm) ($p < 0.001$, Fig. 4).

Furthermore, there was a significantly higher fixation tensile strength result in non-absorbable 5-mm helical ProTack™ with $21.5 \pm \text{SD } 5.5$ N over absorbable 5.1-mm screw-like AbsorbaTack™ with $13.6 \pm \text{SD } 7.3$ N

Table 1 Eleven different laparoscopic ventral hernia fixation devices

Group	Brand	Shaft design	Fixation design	Fixation material	Illustration
1	ReliaTack™	Non-articulating	Tack, 5.1 mm, screw	Absorbable, PGLA	
2	ReliaTack™	Articulating	Tack, 5.1 mm, screw	Absorbable, PGLA	
3	ReliaTack™	Non-articulating	Tack, 7 mm, screw	Absorbable, PGLA	
4	ReliaTack™	Articulating	Tack, 7 mm, screw	Absorbable, PGLA	
5	AbsorbaTack™	Non-articulating	Tack, 5.1 mm, screw	Absorbable, PGLA	
6	ProTack™	Non-articulating	Tack, 5 mm, helical	Non-absorbable, titanium	
7	SorbaFix™	Non-articulating	Tack, 6 mm, screw	Absorbable, PLA	
8	SecureStrap™	Non-articulating	Tack, 7.2 mm, strap	Absorbable, PLG	
9	LiquiBand FIX8™	–	Glues	Absorbable, cyanoacrylate	
10	PDS	–	Transfascial sutures 2-0	Absorbable	–
11	PDS	–	Transfascial sutures 0	Absorbable	–

PGLA poly(glycolide-co-L-lactide), PLA poly(D,L)-lactide, PLG polydioxanone and L(-)-lactide/glycolide copolymer

($p < 0.001$). Notably in this study, absorbable 7-mm screw-like ReliaTack™ was able to deliver similar results with $19.8 \pm \text{SD } 9.4$ N, compared to traditional non-absorbable 5-mm helical ProTack™ ($p = 0.24$). In the choice of different fixation materials, transfascial sutures (PDS 2-0 sutures $26.3 \pm \text{SD } 5.6$ N; PDS 0 sutures $32.6 \pm \text{SD } 8.2$ N) provided far better fixation tensile strength than AbsorbaTack™

($13.6 \pm \text{SD } 7.3$ N) and cyanoacrylate glues LiquiBand FIX8™ ($3.5 \pm \text{SD } 2.4$ N) ($p < 0.001$, respectively).

In comparing the mean fixation tensile strength in the upper, middle and lower abdomen, there was no statistical difference observed (upper abdomen $17.0 \pm \text{SD } 9.4$ N, middle abdomen above the arcuate line $17.6 \pm \text{SD } 9.8$ N, middle abdomen below the arcuate line $16.0 \pm \text{SD } 8.8$ N,

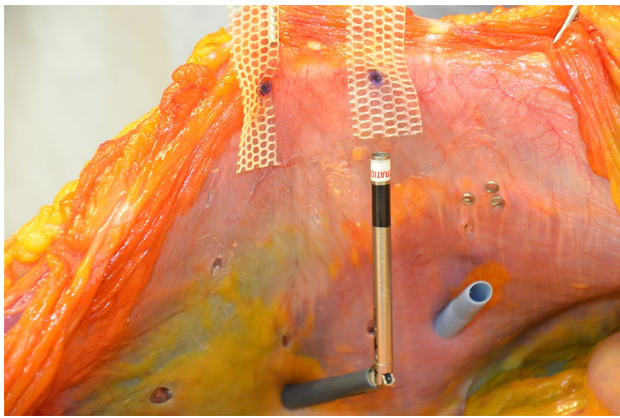


Fig. 1 Inner aspect of the abdominal wall showing the position of articulating fixation instruments with the shaft angled at 65° to place tacks

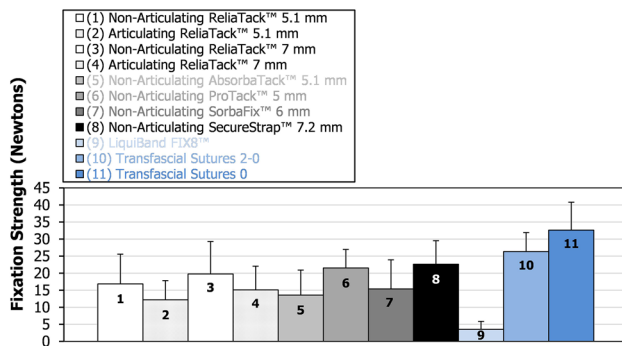


Fig. 2 Overall results of mesh fixation tensile strength in LVHR

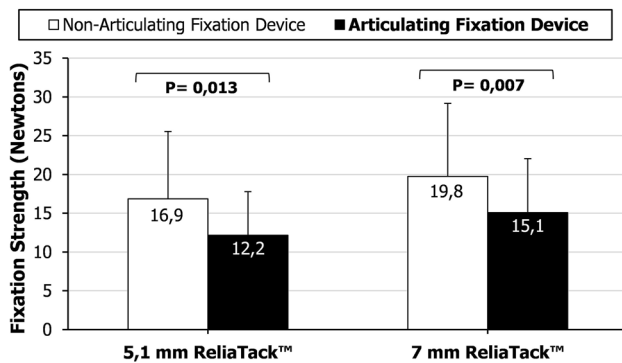


Fig. 3 Higher fixation resistance to tensile stress following laparoscopic non-articulating fixation application

lower abdomen $18.0 \pm SD 10.3$ N). In comparing the mean fixation tensile strength in normal weight and overweight abdomen, there was a significantly lessened fixation capacity in the group with a body mass index of over 30 kg/m^2 ($13.8 \pm SD 8.0$ N vs. $17.9 \pm SD 9.7$ N, $p = 0.044$, Fig. 5).

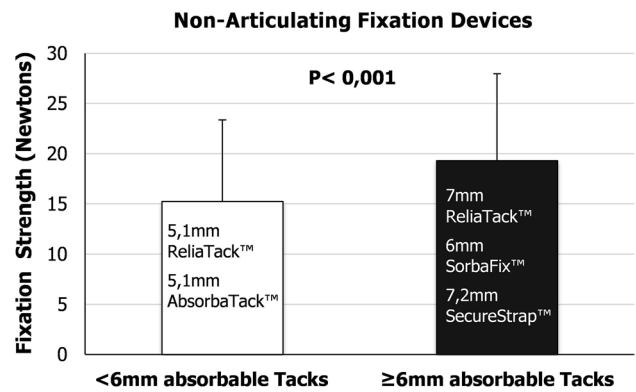


Fig. 4 Absorbable fasteners with greater penetration depths ≥ 6 mm had higher mesh fixation tensile strength

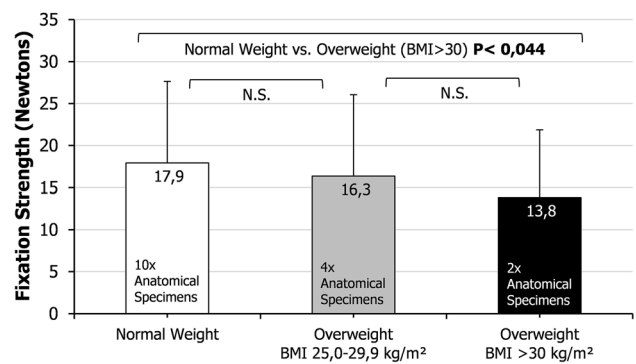


Fig. 5 Deteriorated fixation capacity in overweight abdomen with a body mass index over 30 kg/m^2 in LVHR

Discussion

An articulating shaft in laparoscopic mesh fixation devices is a novel design that allows abdominal accessibility at the fixation weak spot adjacent to the trocar placement. It has been clinically proven to be useful, without any intraoperative or postoperative complications [13]. Furthermore, it reduces the need to place an additional contralateral port to secure the mesh in order to prevent fixation line failure [9]. However, as previously postulated [14], articulating laparoscopic instruments in neutral and fully articulated positions may involve different application forces required to perform the same surgical task. Our study results in terms of mesh fixation suggest that articulating laparoscopic equipment may lack applicable force in the articulating shaft, resulting in decreased mesh fixation strength. Laparoscopic mesh fixation devices require instrument stability to transfer the placement force and to target tack penetration. An articulating shaft that is not ergonomic to use may hinder such mechanism of force transmission. Nonetheless, another publication using animal models

suggests no difference in immediate fixation force between articulating and non-articulating tack application [15]. To simulate the real-life conditions during laparoscopic mesh fixation, there is a shortcoming related to the absence of pneumoperitoneum in the present study. The shape of the pneumoperitoneum changes the plane angle of the abdominal wall and may therefore influence the tack entry angle.

In our material evaluation of tack devices, we were able to demonstrate higher fixation tensile strength in tacks with a length ≥ 6 mm among absorbable materials. Also, non-absorbable titanium tacks were shown to provide stronger fixation strength over absorbable tacks. As is known, increased fixation strength is preferable and in fact required in cases of large ventral hernia [2]. There is, however, prevailing evidence related to the adverse effects of adhesion formation in traditional non-absorbable titanium tacks [5, 6]. In cases of large ventral hernia, we recommend that absorbable tacks with a longer length (therefore greater penetration depths achievable) should be used. But it must bear in mind that potential downsides of deeper penetrating absorbable fixation may cause tissue trauma or bleeding. Non-absorbable titanium tacks should be reserved for exceptional fixation applications, e.g. into bony and ligamentous structures. From a clinical perspective, no absolute superiority in terms of recurrence rate and postoperative quality of life outcomes has been observed between absorbable and non-absorbable materials [7, 8, 16].

LVHR in obese patients has been proven to minimize surgical site infections, without increasing recurrence rates [17, 18]. In our first LVHR series in the year 2006 (unpublicized data), we encountered only early recurrence in obese patients with large hernia. Aside from sudden increases of intraabdominal pressure due to coughing, inappropriate mesh fixation has been pointed out as the main cause of early recurrence [19, 20]. In obese body donators, we were able to demonstrate reduced immediate tensile strength of mesh fixation in the group with a body mass index over 30 kg/m^2 . This is most likely due to the fact that penetration of tacks may only reach the preperitoneal fat and not the fascia in obese patients [21].

In terms of the best choice of laparoscopic mesh fixation, there are divided opinions about the sole use of tacks or a combination using other approaches. For this reason, we provided an overview of the immediate fixation tensile strength of tacks, glues and transfascial sutures (Fig. 2). Glues have the lowest fixation tensile strength. However, they are a good choice for additional mesh fixation above the costal margin in order to prevent cardiac or lung injuries [2]. Absorbable tacks have good results in the immediate fixation tensile strength, albeit inferior to transfascial sutures. Non-absorbable titanium tacks should be used for exceptional fixation cases involving bony structures, for example, the pubic symphysis. In our own clinical experience, we have found that

a combination of 2–4 transfascial sutures at the edge of the mesh and absorbable tacks with deeper penetration depths would be a good mesh fixation technique for difficult ventral hernia cases. By using non-articulating tackers, an additional access via a 5-mm trocar on the contralateral side is still a reliable solution for any mesh fixation weak spot in difficult ventral hernia operations. In terms of clinical outcomes with mesh fixation, current data still show inconsistent results concerning recurrence and postoperative pain assessment [22, 23]. Additional clinical studies are warranted to investigate the best choice in terms of laparoscopic mesh fixation.

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Compliance with ethical standards

Disclosures The authors Yi-Wei Chan, Zacaria Sow, Dobrica Lukic, Matthias Monschein, Elisabeth Calek, Michael Pretterklieber and Christian Hollinsky have no conflicts of interest or financial ties to disclose.

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