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Reconstructive

Clinically Applied Biomechanics of Mesh-reinforced Ventral Hernia Repair: A Practical Review

Sanjay K.A. Jinka, MD*
Jeffrey E. Janis, MD, FACS†

Background: Ventral hernia repair is inherently prone to recurrence. This article is a practical review that summarizes the literature on the biomechanics of ventral hernia repairs to provide clinically applicable, evidence-based recommendations to reduce hernia recurrence.
Methods: A practical review of all relevant literature in PubMed concerning the mechanics of ventral hernia repairs and the forces involved was conducted in August 2023.
Results: Of the 598 full-text publications retrieved, 29 satisfied inclusion criteria. Among these, 5 articles included enough numeric data for a quantitative analysis of the ultimate tensile strength of the layers of the abdominal wall.
Conclusions: The utilization of mesh in ventral hernia repairs is recommended to strengthen weakened abdominal wall tissue. It is essential to primarily close the anterior sheath with a robust mesh–tissue overlap to promote "load-sharing" between the mesh and the abdominal wall. This approach reduces mesh deformity and stress on fixation points, leading to lower hernia recurrence rates. Minimizing mesh fixation (when placed in the retromuscular plane) can reduce postoperative pain and hospital stay without significantly affecting hernia recurrence. Orienting mesh according to abdominal anisotropy is crucial for reducing mesh stiffness, improving healing, and preventing recurrence. Future studies with advanced computer modeling will continue to provide further insights into mesh biomechanics and abdominal wall healing. *(Plast Reconstr Surg Glob Open 2024; 12:e6294; doi: 10.1097/GOX.0000000000006294; Published online 22 November 2024.)*

INTRODUCTION

Ventral hernia repair is a common procedure in the United States, with more than 350,000 operations performed annually.[1] Hernia recurrence is a major concern in these repairs, with a reported 5-year recurrence rate of up to 44.9% with mesh and 73.7% without mesh.[2,3] Given this substantial difference, the majority of surgeons today rely on mesh to help decrease recurrence rates in ventral hernia repair.[4]

Many articles review the biomechanical properties of mesh and abdominal wall tissue; however, very few of these articles are directed toward practicing surgeons. As a result, there is a paucity of easily understandable, clinically relevant literature that clearly explains the biomechanical benefits of mesh in ventral hernia repair. This article serves to fill this gap by providing a practical review of the salient basic science and translational biomechanics involved in abdominal wall healing after ventral hernia repair. Throughout this review, an emphasis is placed on how mesh augments a repaired abdominal wall and how surgeons may use this information to optimize their practice.

*From the *Department of Plastic Surgery, Wright State University, Dayton, Ohio; and †Department of Plastic and Reconstructive Surgery, Ohio State University Wexner Medical Center, Columbus, Ohio.*

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METHODS

A search of PubMed was performed on August 1, 2023 (Fig. 1). Search terms included a combination of (biomechanics, force, OR mechanical) AND (linea alba, transversus abdominis, rectus sheath, peritoneum, abdomen/abdominal, OR hernia). Article screening and data extraction were performed by 1 independent reviewer (S.K.A.J.). Articles that are unavailable in English and without

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full-text access were excluded. Articles were included only if content focused on human subjects (including cadaveric human models). Of these remaining articles, a subset was identified that included numeric data from human cadaveric tissue models. These articles were used to conduct quantitative analysis of the ultimate tensile strength (UTS) of various layers of the abdominal wall.

RESULTS

The literature search procured 743 articles. Of these, 598 were full-text nonduplicates. The primary review of titles and abstracts excluded 529 articles due to unrelated subject matter. An additional 40 articles were excluded for not including human subjects. The remaining 29 studies satisfied the inclusion criteria and are listed later (Table 1). These studies can be categorized as describing the properties of wound healing, distribution of mechanical loads on the abdominal wall, mesh fixation, anisotropy, and finite element analysis (FEA). Additionally, of the 29 studies, 5 included numeric data regarding the UTS of human cadaveric abdominal wall layers for use in quantitative analysis.

Takeaways

Question: How can the biomechanics of ventral hernia repairs be applied to reduce recurrence rates?

Findings: A practical review of 598 studies, with 29 meeting criteria, revealed from a biomechanical perspective that mesh use is essential to create a robust "load-sharing" abdominal wall repair. Key techniques include closing the anterior sheath, ensuring robust mesh–tissue overlap, and orienting mesh in accordance with abdominal wall anisotropy.

Meaning: Proper mesh orientation, fixation, and positioning in ventral hernia repairs may reduce recurrence. Future studies with advanced computer modeling will continue to provide further insights into mesh biomechanics and abdominal wall healing.

With these 5 studies, tissue from 423 cadaveric donors were analyzed. The average age of donors was 76 years. A total of 197 donors were men and 226 women. In the compiled analysis, the anterior rectus sheath demonstrated an average UTS of 8.75 MPa in the transverse

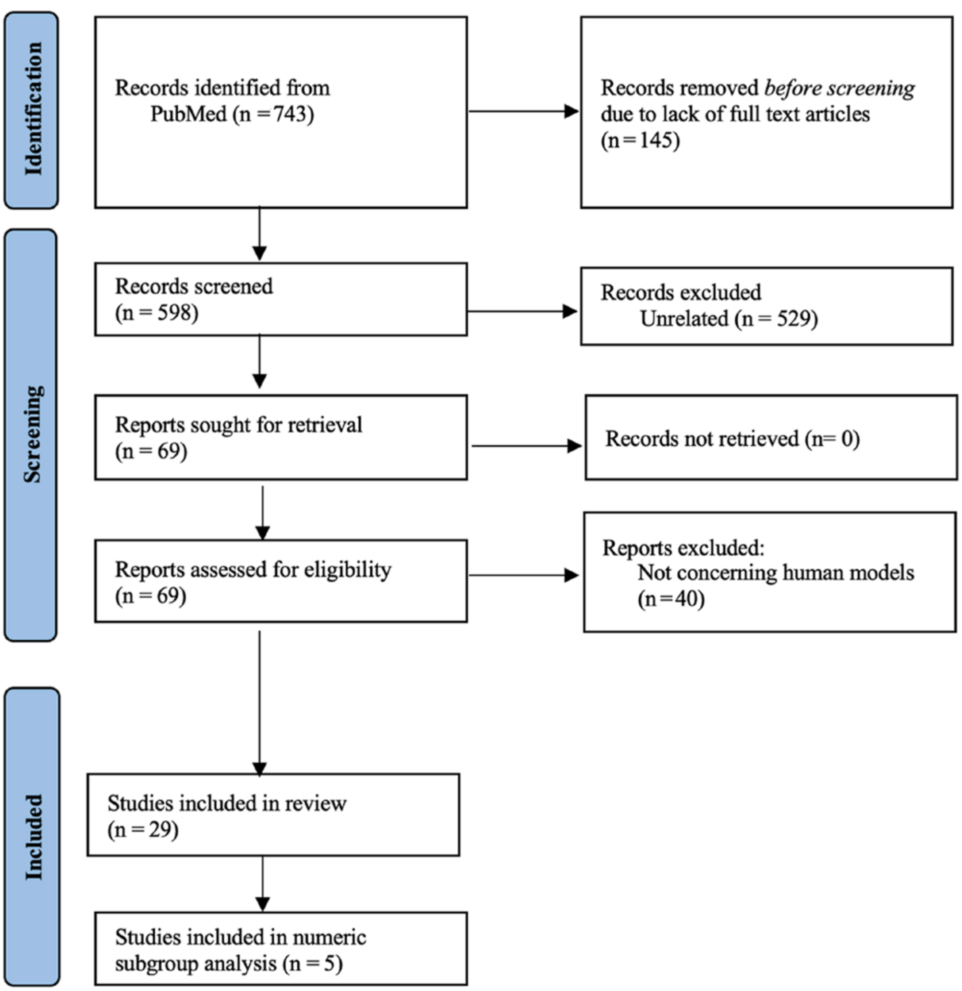

Fig. 1. Citational attrition from literature search.

Table 1. Articles Included in Practical Review

Author/Year	Category	Description	Relevant Data
Pollock and Evans[33]/1989	Wound healing	Stainless steel clips were attached to opposing ends of sutured aponeuroses before the closure of laparotomies (163 cases). Radiographs were taken at 1 mo to measure 30 d fascial separation and patients were followed up for hernia recurrence	A total of 94% of patients with separation of the clips of 12 mm or more at 1 mo developed hernias
Flum et al[3]/2003	Wound healing	A 12-y retrospective review of preoperative incisional repair rates and length of hospitalization based	The 5-y reoperation rate was 23.8% after the first reoperation, 35.3% after the second, and 38.7% after the third
Booth et al[7]/2013	Load distribution	An 11-y retrospective review of patients with AWR comparing hernia recurrence between bridged and mesh-reinforced fascial repairs.	Primary fascial closure with mesh resulted in significantly fewer recurrences/complications than bridged repairs
Hernández-Gascón et al[8]/2011	Load distribution, anisotropy, finite element analysis, and quantitative analysis	A finite element simulation of healthy and partially herniated repaired abdominal wall through a strain energy function under the continuum theory of large deformation hyperelasticity using previously characterized passive mechanical behavior of abdominal wall tissue	In all cases, maximal stresses were higher in an implanted abdomen than in an intact wall model. Additionally, see Table 2 for results
Guérin and Turquier[9]/2013	Load distribution	Finite element and physical model analysis was conducted of passive and active abdominal wall models. Various healthy, damaged, and repaired abdominal wall configurations were included in the analysis	A decrease in mesh–tissue overlap significantly affected the performance of the ventral hernia repair with stress in the mesh being a significantly affected variable
Langer et al[10]/2001	Load distribution	A case report regarding central mesh recurrence after incisional hernia repair	Continuous mesh movement due to changes in intra-abdominal pressure (breathing, working, etc) was found to increase damage at the transitional zone of the fixed and mobile parts of the load-bearing bridged mesh, making it prone to failure
Petro et al[11]/2015	Load distribution	Review of 36 patients who underwent open incisional hernia repair with retrorectus mesh placement for hernia recurrence	Lightweight monofilament polyester mesh was found to have a high incidence of mechanical failure associated with incomplete closure of the anterior fascial layer
Martins et al[12]/2012	Load distribution and anisotropy	A damage model was created to predict the stress–strain behavior of the anterior rectus sheath using laser scanning microscopy to perform a 3-dimensional reconstruction of ventral and dorsal segments	Tested specimens demonstrated both nonlinear and anisotropic responses to high strains
Žuvela et al[39]/2013	Load distribution	A case report regarding recurrent incisional hernias with central mesh rupture.	In all cases, the anterior myofascial layer was not fully reconstructed
Howes et al[6]/1929	Wound healing	An early survey of literature exploring the timeline of wound healing and strength of fascia	The tensile strength of a healing wound is a function of the fibroplastic process. This study is one of the first to define the relative weakness of a wound in the first week of healing (the inflammatory phase) and the importance of the fibroproliferative phase
Etemad et al[42]/2020	Mesh fixation	Outcomes were compared between patients who received mechanical mesh fixation and those who received fixation-free mesh placement	No difference in 30-d recurrence was found. Median length of stay, pain scores, and abdominal wall function scores were worse in groups with mechanical fixation
Ellis et al[41]/2023	Mesh fixation	Outcomes after transfascial mesh fixation were analyzed in open RVHR	No fixation was found to be noninferior to suture fixation in RVHR with synthetic mesh
Dumanian[19]/2020	Wound healing	A commentary on the findings of Etemad et al.[43]	Fixation-free mesh placement requires friction between the mesh and the tissue to be stronger than deforming forces to avoid failure. A fixed mesh meanwhile can better resist these early deformation forces while limiting seroma formation/mesh migration. The noninferiority found in Etemad et al[43] may be secondary to inconsistency in the definition of mesh fixation
Deeken and Lake[23]/2017	Anisotropy	A summary of the current literature related to the anatomy and mechanics of abdominal wall tissue	The human abdominal wall is anisotropic with anisotropy ratios as high as 8–9 for the human linea alba. Anisotropy between the various tissues of the abdominal wall
Todros et al[47]/2017	Anisotropy	Properties of synthetic surgical meshes were reviewed with a focus on the biaxial tensile test, a modality that can reproduce physiologic loading conditions	With computational approaches, the current models can be improved

(*Continued*)

Table 1. *Continued*

Author/Year	Category	Description	Relevant Data
Grantcharov and Rosenberg[24]/2001	Anisotropy	Review of randomized control trials comparing postoperative complications after vertical and transverse abdominal incisions	Transverse incisions have a lower incidence of incisional hernias secondary to anatomical and physiological principles of abdominal wall mechanics
Ajao[49]/2007	Anisotropy	A review of a variety of abdominal incision techniques.	Transverse incisions are preferred for cosmetic scar healing
Yu and Ma[25]/2020	Load distribution and anisotropy	Mechanical properties of heavy and lightweight mesh were compared using a variety of loading conditions	The mesh should be placed in the proper direction to comply with the anisotropy of the abdominal wall during the operation. The area of mesh fixation was highly susceptible to damage
Pott et al[50]/2012	Anisotropy	Maximum force, breaking strain, and stiffness were computed for several different meshes	Due to the anisotropic nature of the abdominal wall, the orientation of mesh is an important consideration that should be described by mesh manufacturers
Binnebösel et al[26]/2007	Anisotropy	A physical incisional hernia model was created using a pressure chamber, an elastic silicone pad as the peritoneal sac, and a silicone mat with muscle tissue to represent the abdominal wall. Mesh was implanted in onlay and sublay configurations and its response to pressure was observed	Mesh with anisotropy should be oriented with the most stretchable axis in the direction of least overlap with native abdominal tissue
Doneva and Pashkouleva[51]/2018	Anisotropy	Mechanical compatibility of hernia mesh and human abdominal fascia were assessed with uniaxial tensile tests	The majority of mesh from major manufacturers display anisotropic qualities
Tomaszewska et al[30]/2018	Anisotropy	Abdominal implant stiffness was studied with ex vivo experiments with cyclic pressure loading	After cyclic loading mesh deforms particularly at the fixation points
Lubowiecka[32]/2015	Finite element analysis	A material model of implant-based reconstruction was created to estimate the repair persistence of different mesh materials	The proposed model was found to accurately simulate the behavior of implanted mesh
Hollinsky and Sandberg[5]/2007	Anisotropy/numeric analysis	Cadaveric tissue was exposed to tensile loads to elucidate ultimate tensile strength	See Table 2
Todros et al[52]/2018	Finite element analysis	A virtual solid model of the abdominal wall was created from MRI scans of healthy subjects	The model may be used to better understand abdominal wall surgical repair/mesh characteristics and for presurgical planning
Kubo[54]/1994	Load distribution	Abdominal muscle strength was measured in healthy subjects of various ages with a grip dynamometer	A decrease in abdominal muscle strength is observed due to aging
Rath et al[14]/1997	Anisotropy/quantitative analysis	Biomechanical testing was conducted on cadaveric tissue with a dynamometer	See Table 2
Astruc et al[48]/2018	Anisotropy/quantitative analysis	Uniaxial testing was conducted on cadaveric tissue of both genders	See Table 2
Kirilova et al[15]/2011	Anisotropy/quantitative analysis	Mechanical properties of cadaveric tissue were studied with 1-dimensional tensile behavior curves	See Table 2

AWR, abdominal wall reconstruction; MRI, magnetic resonance imaging.

Table 2. Ultimate Tensile Strength of Ventral Abdominal Wall Layers

Layer	N	Male/Female	Mean Age, y	Transverse, MPa	Longitudinal, MPa	Reference
Anterior rectus sheath (above arcuate line)	30	14/16	83	—	4.5	30
Anterior rectus sheath (above arcuate line)	66	30/36	77	8.1	3.4	27
Anterior rectus sheath (below arcuate line)	12	0/12	46	12.8	3.4	11
Anterior rectus sheath (below arcuate line)	8	6/2	78	12	0.95	31
Anterior rectus sheath (below arcuate line)	66	30/36	77	8.5	3.4	27
Posterior rectus sheath (above arcuate line)	8	6/2	78	7.0	1.7	31
Posterior rectus sheath (above arcuate line)	66	30/36	77	5.6	1.9	27
Transversalis fascia	66	30/36	77	5.0	2.1	27
Transversalis fascia	14	9/5	66.5	8.9	3	32

dimension and 3.7 MPa in the longitudinal dimension (182, Tables 2, 3). When compared with the UTS of the posterior rectus sheath, the anterior rectus sheath was 1.5 and 1.8 times stronger in the transverse and longitudinal dimensions, respectively. When compared with the transversalis fascia, the anterior rectus sheath was 1.5

Table 3. Compiled Ultimate Tensile Strength of Ventral Abdominal Wall Layers

Layer	N	Mean Age, y	Transverse, MPa	Longitudinal, MPa	Citation
Anterior rectus sheath (above arcuate line)	96	78.9	8.1*	3.7	27,30
Anterior rectus sheath (below arcuate line)	86	72.8	9.4	3.2	11,27,31
Posterior rectus sheath (above arcuate line)	74	77.1	5.8	1.9	27,31
Transversalis fascia	80	75.1	5.7	2.3	27,32

*N = 30, mean age = 83 y.

times stronger in both the transverse and longitudinal dimensions.

DISCUSSION

Wound Healing

Our review reveals that midline fascial disruptions that occur within the first 30 days after hernia repair may lead to more than 90% hernia recurrence.[33] This can be explained by the basics of wound healing. To review, wounds undergo 3 phases of healing: the inflammatory phase (up to 7 days), the fibroproliferative phase (up to 4 weeks), and the maturation (remodeling) phase (3 weeks to 3 months).[34–38] The inflammatory and fibroproliferative phases are especially important, as the abdominal wall only heals up to 34% of the final tensile strength during this 30-day period.[13] Most of the abdominal wall strength comes in the remodeling phase from the replacement of loose type III collagen with acellular interlaced type I collagen. Resultantly, surgeons should be aware that the peak tensile strength of a healing abdominal wall is not reached until approximately 90 days postoperatively. It should also be noted that approximately two-thirds of the final tensile strength is achieved after 6 weeks, even though temporally speaking, this is the halfway mark to final strength.[6,13,38] The remaining third is achieved over days 46–90. Therefore, it is reasonable to suggest that patients should refrain from returning to normal activity until at least 6 weeks postoperatively as this is when most final tissue strength returns. For optimal results from a wound healing perspective, waiting 90 days to resume activities that induce sustained abdominal wall stress may even be recommended. The benefits of this 90-day waiting period, however, should be balanced against concerns of poor patient compliance over an extended period, risk of venous thromboembolism from limited activity, and diminished quality of life for patients seeking to return to baseline activities. Practically, the postoperative plan should be tailored to each patient's lifestyle and venous thromboembolism risk/anticoagulation plan to limit the sustained strenuous activity for 6 weeks and to be conservative with wound healing ideally for 90 days, if possible. A stepwise approach may also be considered, with full restrictions for the first 6 weeks and gradually ramping up activity subsequently until postoperative day 90 (3 months).

Our review also highlights that wounds ultimately only heal to 80% of their original tensile strength, even after the 90-day mark is reached.[6] This is exacerbated in recurrent hernia repair whereby the re-repaired tissue only achieves 80% of that already reduced capacity, an effective total strength of approximately 64%. This helps explain why recurrence rates after ventral hernia repair have been reported as 77% higher after a reoperation when compared with the index hernia operation.[2] Practically, it is essential to counsel patients on the risks of recurrence, particularly in reoperations. To augment intrinsically weakened abdominal fascia and reduce recurrence rates, most surgeons used mesh to provide exogenous strength.

Bridging Mesh

One consideration when using mesh for ventral hernia repair is whether primary closure of the fascia is necessary, that is, the effectiveness of mesh-reinforced primary musculofascial reapproximation versus bridged mesh repairs. Bridged repairs are known to have a significantly higher hernia recurrence rate (56% versus 8%, across a 31-month average follow-up period), more complications (74% versus 32%, across the same 31-month period), and a shorter time to recurrence (9 times faster) compared with mesh-reinforced primary musculofascial reapproximation.[7] Research utilizing FEA demonstrates that increased overlap of mesh with tissue lowers recurrence rates by spreading stress across a larger area of the abdominal wall. In contrast, bridging mesh concentrates stress at the mesh–tissue interface and may also fail via central rupture or bulging.[8,9] Biomechanically, this means that a mesh-reinforced primary musculofascial closure functions as a *load-sharing* system, distributing stress across multiple components, although bridging mesh operates as a *load-bearing* system where each component of the repair carries a significant portion of the stress by itself rather than acting together synergistically.[10–12,39]

The example of repairing a bony fracture can be used to further illustrate the concept of load-sharing versus load-bearing. In cases where the fracture is comminuted or the bone atrophic, poor or no bone-to-bone contact at the fracture line may be present. Resultantly, a load-bearing fixation is necessary. In this scenario, the prosthetic/fixation device (plate) serves as a "bridge" between the fractured pieces of bone, anchoring them in place so they can grow into each other, heal, and eventually become a load-bearing structure themselves.[40,41] Meanwhile, in an isolated simple fracture where robust bone-to-bone contact is present at the fracture line, fixation hardware can be placed that reinforces this bone-to-bone contact. In this way, the fixation hardware is "sharing" the load at the fracture site with the native bone instead of bearing the entire load itself while waiting for the bone to grow together.

Using the same principles, in the case of an abdominal wall bridged mesh repair, the mesh is entirely load-bearing by itself, as there is no fascia-to-fascia contact. This means any stress placed on the mesh will be transferred to the mesh–tissue interface. In contrast, when mesh augments primarily reapproximated musculofascial tissue, this serves as a load-sharing construct. In this case, any stress placed on the mesh is distributed between the mesh–tissue interface and the native abdominal wall tissue together as a composite. This distribution of force is what makes mesh-reinforced primary musculofascial repair so effective.

The takeaway is that to create a stronger load-sharing abdominal repair instead of a weaker load-bearing structure, a bridged repair should be avoided when possible. This practical point is demonstrated clearly by the results of the Booth et al[7] study, whereby all patients with bridged repairs with at least 4 years of follow-up after initial repair experienced computed tomography scan–proven recurrence. Closure of the anterior rectus sheath, specifically, is essential to maximize load-sharing and prevent this recurrence.[14,15] This is demonstrated by our quantitative analysis showing that the anterior rectus sheath is 1.5–1.8 times stronger in the transverse and longitudinal dimensions than both the posterior sheath and transversalis fascia. In cases where the anterior layer cannot be closed, utilization of a heavy-weight mesh has been described to help bear abdominal loads and mitigate hernia recurrence secondary to central rupture and mesh bulging.[39] Our quantitative analysis, however, suggests that this heavy-weight mesh may not be necessary if the anterior rectus sheath was repaired primarily.

Mesh Fixation

Another aspect to consider when using mesh is whether to perform mesh fixation. Mesh can be secured with sutures, tacks, or fibrin glue, or left unfixed.[42] A 2020 study comparing outcomes of fixated mesh (FM) versus non-FM (NFM) in open retromuscular ventral hernia repairs (RVHRs) showed no difference in composite recurrence rates at 30 days, 1 year, 2 years, and 3 years, or in rates of hospital readmission, reoperation, or wound events between the techniques.[43] The study went on to show median length of stay and reported that pain was decreased in patients with NFM over FM. Abdominal wall function scores were higher in the NFM group as well. A more recent 2023 prospective randomized clinical trial supports these findings, with NFM demonstrating noninferior 1-year hernia recurrence compared with FM in open RVHRs specifically.[44] The literature comparing FM and NFM in the context of laparoscopic inguinal hernia repair also supports these findings, with no significant differences found in the risk of hernia recurrence or surgical site infection.[16,45,46] These studies went on to confirm that NFM was associated with reduced operative time, postoperative pain medication use, and length of hospital admission compared with FM.

The differences in pain and length of admission may stem from mesh fixation, potentially causing nerve entrapment, trauma, or ischemia.[17] However, the large mesh sizes used in these studies (average 720 cm^2 in the 2020 RVHR study) might have exacerbated these issues, as they required fixation to be placed laterally in the abdomen, a region where nerves are larger and more susceptible to impingement.[43] Nevertheless, the observed decrease in postoperative pain with NFM compared with FM is a clinically significant consideration.

From a biomechanical perspective, the equivalent recurrence rates between NFM and FM seem counterintuitive. Although patients are instructed to not exert themselves postoperatively, even coughing has been shown to generate intra-abdominal pressure above 100 mm Hg.[18] NFM relies solely on friction within the retromuscular space/pocket to create a load-sharing environment capable of withstanding these intra-abdominal pressures, whereas FM benefits from the robust mesh–tissue interface provided by fixation.[19] This fixation also serves to prevent mesh migration, seroma, or the creation of a potential space. Taken together, recurrence rates should theoretically be higher in the NFM groups, and future computer simulations may help to better understand the biomechanical basis for its noninferiority. Practically, the current literature strongly suggests that to optimize pain management, admission duration, and operative time without compromising the integrity of the repair, the mesh should not be fixated when performing retromuscular repairs.

However, this cannot be extrapolated to onlay or underlay repairs, as there is no defined self-contained pocket to hold the mesh in place. Much like a skin graft requires both fixation and a bolster to promote a tight interface and graft take, mesh placed in these locations requires a taut, flat, wrinkle-free interface to promote integration.[20–22]

Anisotropy and Mesh

Understanding abdominal wall anisotropy can also assist in better understanding the interplay between biomechanics and abdominal wall reconstruction. Anisotropy refers to how structures respond to forces differently depending on the direction.[23,47,48] This is similar to wood, which is stronger along the grain versus weaker across it. In the case of the abdominal wall, our quantitative analysis shows higher average strength in all abdominal wall layers in the transverse dimension compared with the longitudinal (Tables 2, 3). Therefore, the abdominal wall is more compliant along the cephalocaudal vector (longitudinal) and experiences more average tension along the horizontal vector (transverse). This higher tension in the horizontal dimension explains why transverse abdominal incisions are associated with less pain and better long-term scar outcomes cosmetically when compared with vertical incisions.[24,49]

Both synthetic and biological meshes mimic this anisotropy of native tissue.[8,23,25–29,47,50,51] (**See Video [online],** which demonstrates the anisotropy of synthetic mesh.) Practically, surgeons should consider orienting the mesh, taking these anisotropic properties into account. Failure to do so can lead to mesh deformation, abdominal wall rigidity, higher peak forces at the mesh–tissue interface, and ultimately higher likelihood of hernia recurrence.[28,30] When mesh is oriented as per its anisotropic properties, tissue ingrowth augments mesh's load-sharing properties and enhances its long-term durability.[27,31] Despite these benefits, at present, manufacturers do not share guidelines regarding mesh orientation in accordance with anisotropy. Gently stressing mesh before the placement in the abdomen, as demonstrated in the video **(online)**, may allow a surgeon to determine which vector demonstrates greater compliance and should accordingly be oriented in the cephalocaudal dimension of the abdomen.

Table 4. Practical Takeaways Regarding Ventral Hernia Repairs

Patients should refrain from returning to strenuous activities for at least 6wk postoperatively and up to 90 d for patients for whom this is doable	All patients must be counseled on the increasing risk of recurrence following each reoperation
Primary reapproximation of the anterior rectus sheath with mesh placement should be common practice in ventral hernia repair, when possible, instead of simply using bridging mesh. This maximizes "load-sharing." If the anterior rectus sheath cannot be closed, heavier mesh may be indicated	Nonfixation of retromuscular mesh is preferred over fixation to optimize pain management, admission duration, and operative time. Onlay and underlay mesh will still typically require fixation
Surgeons should orient mesh in accordance with the properties of abdominal wall and mesh anisotropy. In other words, the more compliant vector of the mesh should be oriented in the cephalocaudal vector	

Computational Modeling/FEA Simulations

Our review found several previous FEA simulations of the human abdominal wall, yet most have not produced clinically applicable results.[8,9,32] This could be because these models often overlook the anisotropic nature of abdominal tissue, treat all layers as uniformly thick, and lack validation with sufficient experimental data to accurately represent layer interactions.[5] With further research, computer modeling could become clinically beneficial for preoperative planning. For instance, simulations based on a patient's computed tomography scan might enable surgeons to select the best prosthesis, mesh orientation, and fixation method for each unique case. Although this technology is not currently available, virtual solid models of the abdominal wall have been generated from healthy patient scans.[52] Coupled with advancements in artificial intelligence and machine learning, it is plausible that the necessary technology for such applications will soon be commercially viable.

Limitations

This practical review has several limitations worth noting. First, there is a paucity of literature regarding computer simulations and the biomechanics of the abdominal wall. We suspect this will quickly improve with recent advances in artificial intelligence and computer modeling. Our review is also subject to publication bias inherent in the available source literature. Also, due to the variable mechanics of biologic mesh, this study did not identify literature specifically comparing the biomechanical properties of synthetic versus biologic mesh.

Concerning our numeric analysis, a key limitation is the small number of studies included (5), although the total sample size across these studies was substantial (423). Another limitation is that the average age of the tissue samples used in our analysis falls within the range of 70–80 years, reflecting our reliance on cadaveric tissue donors exclusively. In contrast, the average age of patients undergoing ventral hernia repair is notably younger, around 56.5 years.[53] This highlights a potential lack of generalizability to the younger populations who typically undergo ventral hernia repair. Nevertheless, our findings that the anterior rectus sheath is the strongest fascia among the studied tissues and that the abdominal wall exhibits substantial anisotropy holds across all age groups, lending credibility to our numeric analysis and subsequent recommendations.[54] Another limitation is that the cadaveric samples included in our quantitative analysis did not include patient characteristics (smoking status, diabetes, and obesity).

CONCLUSIONS

The anterior rectus sheath is, on average, more than 1.5 times stronger than the posterior rectus sheath and transversalis layers in both the horizontal and vertical dimensions. However, the tissue only heals to 34% of its peak tensile strength in the first 30 days. Mesh is therefore recommended to reinforce native tissue strength, particularly in the early postoperative period when most recurrences are prone to occur. Primarily reapproximating the anterior rectus sheath and ensuring a robust mesh–tissue interface is critical to permit load-sharing between the mesh and native abdominal tissue, thereby distributing forces more effectively than a bridged mesh, which is a load-bearing (and weaker) construct. Fixation of the retromuscular mesh may not be necessary to ensure this load-sharing occurs. Furthermore, nonfixation has been associated with increased pain control and reduced length of hospital stay postoperatively. Taking care to orient mesh as per the anisotropic properties of native abdominal wall tissue is essential to improving the load-sharing ability of mesh and reducing hernia recurrence in the long term. Future studies with computer modeling may continue to elucidate the biomechanical properties of the healing abdominal wall. With continued innovation, we hope to see computer models allow for customized mesh selection and improved preoperative planning tailored to each patient (Table 4).

Jeffrey E. Janis, MD, FACS
Department of Plastic and Reconstructive Surgery
Ohio State University
Columbus, OH 43212
E-mail: Jeffrey.Janis@osumc.edu
X (Twitter): @jjanismd
Instagram: jeffreyjanismd

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