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ORIGINAL ARTICLE

Can surgeons accurately identify mesh type when interpreting computed tomography scans after ventral hernia repair?

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Abstract

Background Recurrent ventral hernia repair can be challenging due to scarred tissue planes and the increasing complexity of disease related to multiple recurrences. Given the challenges of acquiring complete and accurate prior operative reports, surgeons often rely on computed tomography (CT) scans to obtain information and plan for re-operation. Still, the contribution of CT scans and the ability of surgeons to interpret them is controversial. Previously, we examined the ability of surgeons to determine prior operative techniques based on CT scans. Here, we assessed the accuracy of expert abdominal wall reconstruction (AWR) surgeons in identifying the type of prior mesh using CT imaging.

Methods A total of 22 highly experienced AWR surgeons were asked to evaluate 21 CT scans of patients who had undergone open ventral hernia repair with bilateral transversus abdominis release utilizing mesh. The surgeons were required to identify the mesh type from a multiple-choice selection. Additionally, negative controls (patients without a history of prior laparotomy) and positive controls (patients with laparotomy but no ventral hernia repair) were incorporated. The accuracy of the surgeons and interrater reliability was calculated.

Results The accuracy rate of the surgeons in correctly identifying the mesh type was 46%, with heavy-weight synthetic mesh (HWSM) being identified only 35.4% of the time, Strattice mesh and medium-weight synthetic mesh (MWSM) were identified at 46.3%, and 51.8%, respectively. The interrater reliability analysis found a moderate level of agreement 0.428 (95% CI 0.356–0.503), and the repeatability measure was poor—0.053 (95% CI 0–0.119); this indicates that surgeons cannot reliably replicate the identification process.

Conclusions Surgeons' ability to accurately identify the type of previous mesh using CT scans is poor. This study underscores the importance of documenting the type of mesh used in the operative report and the need for standardized operative notes to improve the accuracy and consistency of documentation.

Keywords Ventral hernia repair · Computed tomography (CT) · Interpretation · Accuracy · Interrater reliability · Reoperation · Mesh type

Introduction

Management of recurrent ventral hernias remains a challenge for hernia surgeons, with an estimated 23–41% rate of recurrence after the first repair [1]. The complexity likely relates to multiple factors, including the heterogeneity in operative approaches, techniques, and mesh types utilized. Recurrent hernia repair increases surgical complexity, is associated with longer operative time, and increases patient morbidity [2, 3]. Planning of these operations is greatly aided by understanding the detailed history of prior procedures, the type of mesh used, and the plane in which it was placed. However, acquiring this history through prior

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operative reports can prove challenging and may require a substantial investment of time and resources. Additionally, essential surgical details are often deficient or imprecise, even if all operative dictations are obtained [4, 5]. Given the challenges associated with acquiring complete and accurate prior operative reports, surgeons often rely on computed tomography scans to obtain information and plan for re-operation.

Considerable debate exists as to the value and contributions of a preoperative CT scan to bridge the gap in missing surgical history for patients with recurrent ventral hernias, specifically regarding the ability to identify the presence, location, and type of mesh device. Several peer-reviewed publications have described or alluded to the purported radiographic appearance of mesh on imaging, including a contemporary chapter authored by hernia surgeons in a textbook entitled "Fundamentals of Hernia Radiology" [6–9]. Although our group performs a high volume of re-operative hernia surgery, and we therefore commonly recommend CT imaging as part of routine preoperative planning, we have not traditionally utilized CTs as a reliable indicator of the prior type of mesh device placed at the time of the preceding operation [10]. We have largely utilized these images for assessing the location/size/morphology of the hernia defects, additional characteristics such as loss of domain, patency of the deep inferior epigastric vessels, or radiographic appearance of the rectus abdominis muscles, which may be helpful to predict operative time and/or anticipate technical challenges.

One of our recent prospective randomized blinded trials received a comment suggesting that "a trained radiologic assessor should be able to identify the presence of a synthetic mesh on a computed tomography or ultrasonography scan, effectively unmasking the intervention the patient had" [11]. Although we responded accordingly that we would respectfully disagree that synthetic mesh can be identified on a follow-up computed tomography scan, we found the suggestion of sufficient provocation to warrant further academic inquiry [12]. Building on previous similar work from our group demonstrating the inability of expert abdominal wall reconstruction surgeons to identify the type/operative approach to repair of prior ventral hernia repair utilizing CT imaging, we aimed to determine if expert abdominal wall surgeons could accurately identify mesh type utilizing CT imaging when agnostic to the known operative details [13].

Methods

Study design and patient selection

Following approval from the Institutional Review Board (IRB), 22 highly experienced abdominal wall reconstruction (AWR) surgeons, comprising eight surgeons from the Cleveland Clinic Foundation (CCF) and 14 from 12 different institutions worldwide, were enrolled to evaluate 21 de-identified CT scans of patients who had undergone surgery 2 years prior. Representative images of mesh based CT scans are presented in Figs. 1, 2 and 3. All surgeons are fellowship-trained and considered experts in the field of AWR. Surgeons independently evaluated the 21 CT scans in axial, coronal, and sagittal views. The surgeons were asked to identify the type of mesh used in the previous surgery from a multiple-choice selection of heavy-weight synthetic mesh (HWSM), medium-weight synthetic mesh (MWSM) and Strattice mesh. The surgeons were blinded to the type of mesh used and unaware of the number of each type of mesh included. The study also included CT scans from two control arms: a negative control arm consisting of patients who had never undergone abdominal surgery and a positive

Fig. 1 A screenshot of an axial view from a CT scan video showcasing a patient with a heavy-weight synthetic mesh

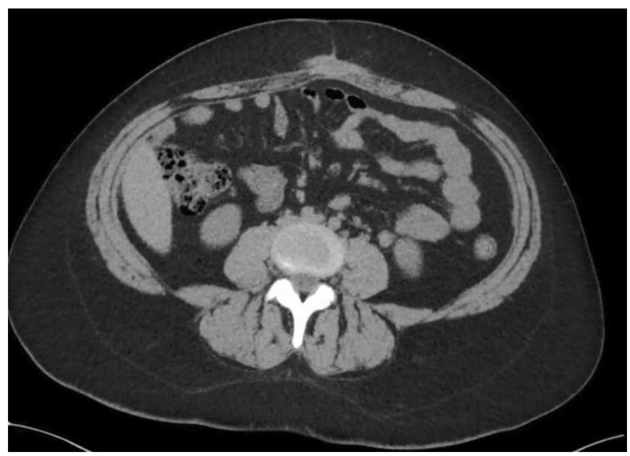

Fig. 2 A screenshot of an axial view from a CT scan video showcasing a patient with a medium weight synthetic mesh

Fig. 3 A screenshot of an axial view from a CT scan video showcasing a patient with a Strattice mesh

control arm comprising patients who had undergone laparotomy without ventral hernia repair. All the surgeons were aware of the control scans included in the study.

This study was conducted at the Cleveland Clinic Center for Abdominal Core Health (Cleveland Clinic Foundation, Cleveland, Ohio). Hospital and personal health information (PHI) were kept anonymous. The CCF's electronic medical record (EMR) was used to identify patients who had undergone ventral hernia repair at CCF. A manual chart review was performed by a research fellow to review each patient's operative reports, confirm the type of mesh used, and select a CT scan approximately 2 years after surgery. CT scans were selected for patients who had previously undergone open transversus abdominis release with either HWSM, MWSM, or Strattice mesh repair. The HWSM refers to PROLENE® Mesh, a polypropylene mesh with a density of 76 g/m^2 produced by Ethicon. The MWSM corresponds to Bard™ Soft Mesh, a polypropylene mesh with a density of 43 g/m^2. Strattice™ mesh is a non crosslinked porcine dermal biological mesh. CT scans were excluded if patients had multiple meshes, had undergone hernia repair for types of hernia other than ventral hernia, had prior ventral hernia repair other than open transversus abdominis release or had evidence of hernia recurrence. The CT scans for both control arms were selected through a manual chart review of CCF's EMR. This involved reviewing all operative reports and history and physical (H&P) notes to confirm the absence of prior surgery in the negative control group and ventral hernia repair in the positive control group. Eligibility was also confirmed by reviewing operative reports from other institutions, where available.

Upon receiving the participants' approval, an information email was dispatched to each participant, explaining the questionnaire. Along with the email, a Microsoft PowerPoint file was also sent, including five CT scans of each type of mesh HWSM, MWSM, and Strattice mesh, as well as three positive and three negative controls (Table 1). Each PowerPoint slide displays axial, coronal, and sagittal views of a CT scan video. Participants were given the freedom to scroll through the CT videos and assess the mesh type without any time restrictions. Data collection was made by a web-based questionnaire created using the Google Forms platform (USA), designed for individual self-completion. The questionnaire was divided into two parts: the first (questions 1–7) gathered general professional information about surgical experience, and the second (questions 8–28) focused on the 21 CT scans. A pilot test involving 7 AWR surgeons was conducted to gain a better understanding of the appropriate presentation of CT scans and to aid in modifying the questionnaire. It is worth noting that the CT scans used in the pilot test differ from those utilized in the main study. The questionnaire was subsequently distributed to the study participants.

Table 1 Distribution of meshes types and controls represented in the total cohort

Type of mesh	Overall ($N=21$)
HWSM	5
MWSM	5
Strattice mesh	5
Negative control	3
Positive control	3

Study outcomes

The study's primary outcome was to evaluate the accuracy of surgeons in interpreting CT scans in identifying the type of mesh employed in previous hernia repair. In addition, we aimed to assess the interrater reliability level among surgeons, which measures the extent of concordance among surgeons rather than the correctness of their responses. Moreover, to determine the consistency of individual surgeons in recognizing the same type of mesh used, we also calculated repeatability (R).

Statistical analysis

Due to the absence of objective tools for evaluating surgeon accuracy in CT interpretation after ventral hernia repair, calculating a sample size based on existing literature was impossible. Therefore, we relied on a previous study performed by our group, which evaluated 21 CT scans among 15 surgeons to estimate accuracy and interrater reliability [13]. As a result, we considered a sample size of 21 CT scans to be sufficient for this study.

Surgeon accuracy was assessed based on the percentage of accurately identified CT scans for each category of mesh type. The Incident Rate Ratio (IRR) was also employed to determine accuracy. IRR is a measure that accounts for variability within the same surgeon and is akin to odds ratios. An IRR value greater than 1 indicates greater ease in identifying an object, while a value less than 1 indicates difficulty. In this study, the IRR value of HWSM was utilized as a reference point. Interrater reliability assessment measures the degree of agreement among the surgeons, whereby the measurement acknowledges their consensus even if their responses are incorrect. The benchmark range for the agreement coefficient is classified as poor (<0.2), fair (0.2–0.4), moderate (0.4–0.6), good (0.6–0.8), and very good (0.8–1). Repeatability (*R*) was measured to evaluate if an individual surgeon correctly answered the same type of mesh used in a reproducible manner. When the value of *R* is equal to 1, it is deemed satisfactory, while figures further from 1 are considered unsatisfactory (Table 2). Statistical analyses were conducted using SAS software (version 9.4; Cary, NA) or R software (version 4.0.0, 2020-04-24; Vienna, Austria).

Results

22 AWR expert surgeons evaluated 21 CT scans. All participating surgeons had undergone fellowship training in either AWR or Minimally Invasive Surgery, with 90.9% practicing at academic medical centers. 60% reported performing 10–20 non-complicated hernia surgeries per month, while 36% declared conducting more than 20 non-complicated hernia surgeries monthly. 18% reported performing 5–10 complex AWR surgeries monthly, whereas 55% declared conducting over ten complex AWR surgeries monthly.

The correct rate was used as an outcome to describe the accuracy among surgeons. Since 22 surgeons interpreted 5 cases of each mesh type and three negative and positive controls, the correct rate was calculated from a total of 110 (22 × 5) mesh types and 66 (22 × 3) controls. Surgeons were able to identify negative and positive controls with an accuracy of 87.8% and 56%, respectively. HWSM was identified 35.4% of the time, Strattice mesh and MWSM were identified 46.3% and 51.8% of the time, respectively. Overall, surgeons' accuracy in correctly identifying all types of meshes was 44.5% (Table 3). Table 4 depicts the distribution of answers for each category, with the first row representing the correct answer and the columns representing the corresponding answers. In addition to the correct rate, 44.5% of surgeons mistakenly identified HWSM as MWSM, 33.6% misidentified MWSM for HWSM, and 34.5% misidentified Strattice as HWSM.

Accuracy was assessed using the IRR, and the IRR findings were consistent with those obtained from Tables 3 and 4. It was 2.48 times more likely to identify negative controls correctly (CI 1.65–3.72, $p<0.01$) and 1.58 times more likely to identify positive controls correctly (CI 1.01–2.48, $p<0.046$) than HWSM. The ability to identify HWSM from MWSM and Strattice mesh did not differ significantly (IRR 1.46, CI 0.97–2.20, $p=0.068$ and IRR 1.31, CI 0.86–1.99, $p=0.208$, respectively) (Table 5).

The interrater reliability assessment is moderate—0.428 (95% CI 0.356–0.503) (Table 6). The estimated repeatability value is poor—0.053, 95% CI (0–0.119). This implies that if surgeons were asked to replicate their identification of the scans, the likelihood of them obtaining identical answers as before is substantially low.

Table 3 Surgeon accuracy estimated by the proportion of CT scans correctly identified for each mesh type and procedure

Type of mesh/control	Correct proportion (%)
HWSM	35.4
MWSM	51.8
Strattice mesh	46.3
All type of meshes	44.5
Negative control	87.9
Positive control	56.1

Table 2 Statistical measurements for evaluating surgeon's accuracy

Measure tool	Explanation	Variables
Incident Rate Ratio (IRR)	Determine accuracy by assessing variability within a specific surgeon	IRR greater than 1 indicates greater ease in identifying mesh type IRR lesser than 1 indicates difficulty in identifying mesh type
Interrater reliability	Measures the degree of agreement among the surgeons The measurement acknowledges surgeons' consensus even if their responses are incorrect	Poor agreement < 0.2 Fair agreement = 0.2–0.4 Moderate agreement = 0.4–0.6 Good agreement = 0.6–0.8 Very good agreement = 0.8–1
Repeatability—*R*	Evaluate if an individual surgeon can correctly answer the same question in a reproducible manner	*R* = 1—satisfactory R figures further from 1—unsatisfactory

Table 4 Distribution of the corresponding answers for each category

	HWSM $N=110$	MWSM $N=110$	Strattice mesh $N=110$	Negative control $N=66$	Positive control $N=66$	p overall
Answer, N (%)						< 0.001
HWSM	39 (35.5%)	37 (33.6%)	38 (34.5%)	0 (0.00%)	1 (1.52%)	
MWSM	49 (44.5%)	57 (51.8%)	15 (13.6%)	1 (1.52%)	8 (12.1%)	
Strattice mesh	16 (14.5%)	8 (7.27%)	51 (46.4%)	1 (1.52%)	1 (1.52%)	
Negative control	1 (0.91%)	1 (0.91%)	1 (0.91%)	58 (87.9%)	19 (28.8%)	
Positive control	5 (4.55%)	7 (6.36%)	5 (4.55%)	6 (9.09%)	37 (56.1%)	

Table 5 Accuracy assessment using Incident Rate Ratio

Parameter	Incident Rate Ratio	SE	Confidence interval	z	p value
HWSM (intercept)	0.35	0.06	(0.26, 0.49)	− 6.48	< .001
MWSM	1.46	0.3	(0.97, 2.20)	1.83	0.068
Strattice mesh	1.31	0.28	(0.86, 1.99)	1.26	0.208
Negative control	2.48	0.51	(1.65, 3.72)	4.38	< .001
Positive control	1.58	0.36	(1.01, 2.48)	2	0.046
# Random effects					
Parameter	Coefficient	SE	CI_low		
SD (intercept: Surgeon)	0	0.16	0		

SE standard error, *z* z-score, *CI low* lower bound of the confidence interval

Table 6 Interrater reliability assessment

Coefficient	pa	pe	Coefficient value	Coefficient se	95% CI	p value
AC1	0.45	0.04	0.43	0.04	(0.356, 0.503)	0.001

AC1 coefficient, *pa* probability of agreement, *pe* probability of chance agreement, *Coefficient se* coefficient standard error

Discussion

Our study suggests that surgeons' ability to accurately identify the type of mesh used for ventral hernia repair using CT scans is highly incorrect. While the surgeons correctly identified a significant proportion of the negative and positive controls, the proportion of correctly identified all mesh types from a selection of three meshes was 46%. Furthermore, the accuracy rate remains suboptimal after accounting for Incident Rate Ratio and variability between individual surgeons. Detecting heavy weight and Strattice mesh poses the most significant challenge, and distinguishing between HWSM and MWSM or HWSM and Strattice mesh is difficult for surgeons, as evidenced by their remarkably low detection accuracy rates. Although the surgeons demonstrated moderate agreement (interrater reliability—0.428, 95% CI 0.356–0.503), their poor accuracy resulted in frequent misidentification of mesh type, even when an agreement was achieved.

To our knowledge, this is the only research conducted to assess the precision of AWR surgeons in identifying prior mesh types via CT scan. Such analysis is critical given the high incidence of recurrent hernias, the increasing complexity of recurrent hernia repairs resulting from the rising use of meshes, and the emergence of new surgical techniques and mesh planes. Understanding the operative history and the mesh type can significantly assist in making surgical decisions. This knowledge enables the surgeons to assess the feasibility and difficulty of re-entering the same plane, assess the necessity and significance of removing the old mesh, predict the procedure duration, and develop an appropriate preoperative plan. Understanding mesh type may also offer valuable insight into the reason for the failure of the previous repair allowing a better selection of mesh type for the next hernia repair. More specifically, an important difference between HWSM and MWSM lies in the potential for MWSM to fracture [14]. Distinguishing between a central mesh fracture versus failure of fixation or overlap with an HWSM is essential for appropriately planning the second surgery and selecting the appropriate mesh type. Being aware of the higher risk of medium-weight mesh fracture can assist the surgeon in anticipating unique challenges associated with mesh fracture, including the possibility of bowel bulging through the mesh and the risk of bowel injury. Furthermore, in our practice, we have observed a significant distinction between HWSM and MWSM in our re-operative experience in the retromuscular plane. MWSM tends to integrate well with the tissue, making their removal more challenging. Conversely, HWSM is generally easier to resect due to the presence of a distinct plane. In cases where complete resection of the MWSM is not possible and concerns arise about fluid collections, the surgeon may opt to leave the medium-weight mesh on the posterior rectus sheath and place a new mesh over it. However, with HWSM, the surgeon may choose to fully resect the posterior rectus sheath along with the heavy-weight mesh. Understanding the mesh type is crucial for additional reasons, including its implications in medical versus surgical interventions in cases of mesh infections and its role in ensuring safety in cases of manufacturing defects.

The difficulty in identifying prior mesh types on CT scans arises from the absence of clearly defined radiographic features. To our knowledge, none of the available meshes intentionally include radiopaque features that can assist in detecting or serve as a unique "radiologic stamp". Furthermore, our expectations regarding the appearance of mesh on CT scans often differ from its actual appearance. It is commonly believed that increased mesh density corresponds to a more pronounced appearance on CT scans. However, our study found that only 35.5% of the surgeons accurately identified the HWSM, while 44.5% confused it with MWSM. Similarly, the general assumption is that biological mesh will dissolve within 2 years of surgery, resulting in minimal radiological imprint. However, in our study, 46.4% of the surgeons correctly identified the Strattice mesh, but 34.5% confused it with HWSM. As noted in Fig. 3, often the Strattice mesh can still be visualized as a distinct line on the CT scan. These findings are illustrated by the modest level of interrater reliability coupled with the low accuracy level. This indicates that while there is some degree of agreement among surgeons, a substantial portion of these agreements is attributable to incorrect identification of mesh type. Another measurement that illustrates surgeons' inadequacy to accurately identify the mesh type is the poor Repeatability level. This suggests that if the same CT scans were to be re-evaluated by the same surgeons, they would not provide consistent and reproducible answers.

Previously, our group assessed the ability of AWR surgeons to interpret post-operative CT scans to identify prior hernia repair approaches. The study's findings indicate that the surgeons' ability to accurately determine the type of previous ventral hernia repair using post-operative CT scans is inadequate. Consequently, the authors highlight the necessity of relying on medical records in conjunction with CT scans and emphasize the significance of precisely recording the surgical course in the operative report. Our study found the same results concerning mesh-type identifications, and we join the authors' conclusions.

This study has various limitations that must be acknowledged. The sample size of 21 CT scans and 22 surgeons may not be sufficient to predict surgeon accuracy and interrater reliability accurately. Although the CT scans were represented by axial, coronal, and sagittal views, and the reviewers could scroll through the CT videos, the surgeons were unable to adjust the contrast or employ a measuring tool for the Hounsfield units of the tissues. Moreover, including only three types of meshes may restrict the generalizability of the results. For instance, various biological meshes may appear distinctively on CT scans, and their identification may not align with this study's findings. Additionally, the surgeon assessors in this study were highly experienced AWR surgeons, so the outcomes may not apply to all surgeons. Notably, radiologists were not included in this study since they are not typically acquainted with the different mesh variables, and they may not accurately discern the type of mesh utilized in the repair.

Conclusions

Our study highlights the inadequacy of surgeons' ability to accurately determine the type of mesh used in prior hernia repair using CT scans. Because this information is vital for anticipating operative complexity and planning the operative approach, our study underscores the importance of documenting the type of mesh used in the operative report and obtaining prior operative reports through the appropriate resources. Given that CT imaging alone may not accurately identify previous mesh types, use of a standardized operative note may improve the accuracy and consistency of documenting and communicating medical information across healthcare teams.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10029-024-03024-w.

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Author contributions All the authors contributed to the study's conception and design. Material preparation and data collection were performed by NM. The initial drafts of the manuscript were written by NM and ASP. All the authors commented on and revised the manuscript. All the authors read and approved the final manuscript. Ajita S Prabhu supervised the study.

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Data availability The data supporting the findings of this study are available upon request from the corresponding author, Nir Messer, under reasonable conditions.

Declarations

Conflict of interest The authors declare that there are no conflicts of interest related to this manuscript. The study was conducted impartially, and the findings presented in the manuscript are based solely on the analysis and interpretation of the data. Informed consent not required: As the study did not involve human patients or participants, no informed consent was necessary. The data utilized in this research were collected and analyzed in a manner that ensures the privacy and confidentiality of individuals and adheres to the relevant ethical guidelines and regulations. Conflict of interest M.J.R. receives salary support for his position in the leadership of the Abdominal Core Health Quality Collaborative (ACHQC), which is the data source for the present submission; and he receives board member support and stock options from Ariste Medical. A.S.P. has received funding paid to her institution from Intuitive Surgical Inc., personal fees from Medtronic, Intuitive Surgical, CMR Surgical, and Verb Surgical. D.M.K. has no declarations. L.R.B has received honorarium from Intuitive.

Ethical approval The research was conducted in accordance with the ethical principles outlined in Institutional Review Board. The use of data and materials was carried out with proper authorization and in compliance with all applicable laws and regulations.

Human and animal rights In adherence to ethical standards, this chart review study, though devoid of direct human or animal involvement, maintained patient data confidentiality and ethical standards as required by the institutional review board.

Informed consent As this study involved the use of existing data and did not involve direct interaction with human subjects, no patients were enrolled, and therefore, no informed consent was required. The data used in this research were anonymized and de-identified, ensuring the privacy and confidentiality of individuals in accordance with the Institutional Review Board.

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