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Rectus Diastasis

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Rectus diastasis (RD) is a hot topic in surgical practice related to abdominal wall surgery. RD describes the separation of the rectus abdominis muscles and is characterised by widening of the linea alba. This causes the midline to "bulge" when intra-abdominal pressure is increased. RD is not a hernia because it does not have a true fascial defect although it can be associated with primary midline hernias. It is a condition mostly seen in women after pregnancy and, to a lesser extent, in obese male patients. Open repair techniques have been described although nowadays the development of minimally invasive approaches for treating RD, has led to a consideration on the role that these novel techniques may play. Despite the increase in ways of approaching RD there is a lack of consensus on the definition, diagnosis and therapeutic management of RD.

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Editorial: Rectus Diastasis

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Keywords: rectus diastasis, diastasis recti, abdominal wall surgery, hernia, linea alba

Editorial on the Special Issue

Rectus Diastasis

Rectus diastasis (RD) is a hot topic in surgical practice related to abdominal wall surgery. RD describes the separation of the rectus abdominis muscles and is characterised by widening of the linea alba. This causes the midline to "bulge" when intra-abdominal pressure is increased. RD is not a hernia because it does not have a true fascial defect although it can be associated with primary midline hernias. It is a condition mostly seen in women after pregnancy and, to a lesser extent, in obese men. Open repair techniques have been described although nowadays the development of minimally invasive approaches for treating RD, has led to a consideration on the role that these novel techniques may play. Despite the increase in ways of approaching RD there is a lack of consensus on the definition, diagnosis and therapeutic management of RD.

Some of these controversial aspects are discussed in this special issue. Thus, it describes the prepartum anatomy of the abdominal wall in a cohort of nulliparous women, for use as a reference for management of patients with postpartum abdominal wall insufficiency (Woxnerud et al.). Similarly, Ngo et al. provide additional features concerning the type of bulging and the width of divarication. In relation to the diagnosis and symptomatology of RD the study of van Wingerden et al. provides an inventory of the incidence of RD in subjects with chronic back and pelvic pain and Bixo et al. offer us a study aimed to understand the correlation between the post-partum inter-recti distance and functional impairments associated with core instability. Finally, regarding the treatment Katawazai et al. evaluates the impact of the minimal incision repair of rectus abdominis diastasis (MIRRAD) procedure on physical activity, muscle strength, quality of life, and overall satisfaction in women with postpartum and Mandujano et al. show us a valuable algorithmic approach for minimally invasive surgery for symptomatic ventral hernias with diastasis of the rectus abdominis muscle.

The increase in knowledge about RD and how to apply it at general and specific levels may lead to a greater increase in the cost-effectiveness of this process, a reduction in morbidity, and better health-related quality-of life of our patients. Although this special issue does not cover all the aspects that can be considered in the handling/treatment of RD we hope it will be helpful to interested readers and help improve the management of this controversial entity.

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This has been drafted by the Special Issue's only guest editor, ML.

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ML has received consulting fees, lectures, travel support and participation in review activities from BD, Gore, Medtronic and B. Braun. In addition, he is editor-in-chief of the Journal of Abdominal Wall Surgery [JAWS] (unpaid).

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ORIGINAL RESEARCH
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Impact of Minimal Incision Repair of Rectus Abdominis Diastasis on Quality of Life and Stress Incontinence: A Prospective Study

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Aim: This study evaluates the impact of the minimal incision repair of rectus abdominis diastasis (MIRRAD) procedure on physical activity, muscle strength, quality of life, and overall satisfaction in women with postpartum rectus abdominis diastasis (PP-RAD).

Methods: A cohort of 31 female patients, aged 20–50 years, diagnosed with PP-RAD unresponsive to conservative treatment, underwent the MIRRAD procedure. Assessments were conducted preoperatively and 1 year postoperatively, these included the Modified Abdominal Trunk Function Protocol (MATFP), Disability Rating Index (DRI), and Urinary Disability Index (UDI) questionnaires. Physical activity intensity was monitored using accelerometers.

Results: Significant improvements were observed in vigorous physical activities ($Z = -2.352$, $p = 0.019$), vector magnitude counts per minute ($Z = -2.163$, $p = 0.031$), and steps per minute ($Z = -3.131$, $p = 0.002$). DRI showed significant improvements in physical tasks like dressing, walking, and strenuous work (Z ranging from −2.705 to −4.603, $p < 0.001$). UDI indicated significant improvements in urinary symptoms, including reduced frequency ($Z = -2.984$, $p = 0.003$) and less urinary leakage ($Z = -2.357$, $p = 0.018$). MATFP demonstrated gains in back and abdominal muscle strength ($Z = -4.321$, $p < 0.001$) and trunk stability ($Z = -3.991$, $p < 0.001$).

Conclusion: The MIRRAD procedure significantly improves physical strength, trunk stability, and urinary function, enhancing daily activities and overall physical health in women with PP-RAD. Further research is recommended to evaluate long-term outcomes.

Keywords: rectus abdominis diastasis, quality of life, ventral hernia, linea alba, postpartum rectus diastasis

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Abbreviations: MIRRAD, Minimal Incision Repair of Rectus Abdominis Diastasis; RAD, Rectus Abdominis Diastasis; PP-RAD, Postpartum Rectus Abdominis Diastasis; MATFP, Modified Abdominal Trunk Function Protocol; VAS, Visual Analogue Scale; DRI, Disability Rating Index; UDI-6, IIQ-7, Urogenital Distress Inventory-6, Incontinence Impact Questionnaire −7; VHPQ, Ventral Hernia Pain Questionnaire.

INTRODUCTION

Rectus Abdominis Diastasis (RAD) is defined as separation of the rectus muscles by more than 2 cm [1]. It is a common condition where separation of the rectus abdominis muscles results in a widening of the linea alba, the connective tissue running down the midline of the abdomen. This separation is often due to increased intra-abdominal pressure and hormonal changes, which can arise for various reasons, most notably during pregnancy. The expanding uterus can stretch the abdominal wall, leading to RAD during pregnancy. This usually reverts, but in some women this leads to postpartum rectus abdominis diastasis (PP-RAD) [2].

PP-RAD can cause significant functional impairments and a range of symptoms. A primary concern is the instability and weakness of the abdominal wall resulting from compromised muscular and fascial integrity. This instability can weaken core strength and trunk function, potentially affecting the pelvic floor muscles. The condition manifests with both direct and indirect symptoms that can significantly impact daily life and physical activities.

Direct symptoms of PP-RAD include a visible bulge or "pooch" along the midline of the abdomen, especially noticeable during activities that engage the abdominal muscles such as sit-ups or lifting. This can lead to abdominal discomfort and a sense of weakness due to the lack of adequate core support. Research also indicates that PP-RAD can impair trunk biomechanics, triggering a series of musculoskeletal problems [3, 4].

Indirect symptoms linked to PP-RAD include low back pain, pelvic discomfort, and urinary stress incontinence. These occur because the abdominal and pelvic floor muscles provide less support, crucial for maintaining posture, spinal stability, and continence. Studies have shown that women with PP-RAD often report reduced quality of life due to these symptoms, experiencing difficulties in performing everyday tasks, participating in physical activities, or returning to pre-pregnancy exercise routines [1, 2, 5].

In addition to physical symptoms, PP-RAD can have substantial psychological effects. Many women report a negative body image and diminished self-confidence, as the persistent abdominal bulge can make them appear "pregnant," causing social discomfort and emotional distress. Recent studies have linked these body image issues with lower self-esteem and a reluctance to engage in social or physical activities [6].

Complications associated with PP-RAD include an increased risk for hernias along the linea alba, particularly midline hernias where abdominal contents protrude through the weakened fascia. Additionally, PP-RAD can lead to hyperlordosis [7].

Recent research has advanced our understanding of RAD complications and management strategies. A 2021 systematic review published in the *Journal of Women's Health Physical Therapy* highlighted the effectiveness of targeted physiotherapy interventions in managing PP-RAD symptoms [4]. These interventions focus on strengthening deep abdominal muscles and improving pelvic floor function, which can alleviate symptoms like low back pain and incontinence. Studies have shown that surgical correction of PP-RAD enhances functional outcomes such as core strength and pelvic stability. Women who opted for surgical repair reported higher satisfaction with their body image and fewer symptoms related to back pain and urinary incontinence compared to those who chose conservative management [8, 9].

While some women may find relief through physiotherapy and lifestyle modifications, others, particularly those with severe diastasis or associated hernias, may require surgical intervention. A comprehensive understanding of the wide range of symptoms and treatment options is crucial for providing holistic care that addresses both the physical and psychological impacts of PP-RAD [10, 11].

In conclusion, PP-RAD is more than a cosmetic concern; it has profound implications for core function, posture, and overall quality of life. Continued research is refining our understanding and management of this condition, offering hope for effective treatments that enhance both the physical and emotional wellbeing of these women.

The aim of this study was to evaluate the impact of a minimally incision repair of rectus abdominis diastasis procedure on quality of life and daily function.

MATERIALS AND METHODS

Study Design and Participants

This prospective study included women diagnosed with postpartum rectus abdominis diastasis (PP-RAD) with an inter-rectus distance of ≥3 cm. The study was conducted at the Hernia Center, Region Örebro Län, Sweden, from October 2021 to August 2024. The study has been registered at ClinicalTrials.gov. All procedures were performed in compliance with the European Union's General Data Protection Regulation (GDPR).

Inclusion Criteria:

- Female patients aged 20–50 years.
- Diagnosed with PP-RAD with an inter-rectus distance of ≥3 cm.
- At least 12 months postpartum and Unresponsive to conservative treatment.
- Decided against future pregnancies.
- No previous surgery involving the linea alba.

Exclusion Criteria:

- Inability or unwillingness to provide informed consent.
- Contraindications to general anesthesia.
- Pregnant or plan to become pregnant in the future.
- BMI >32 kg/m^2

These patients, aged between 20 and 50 years, were all diagnosed with a minimum inter-rectus separation of 3 cm. After attempting conservative treatment without satisfactory improvement, they opted for surgical repair. To be eligible for the study, participants were required to be at least 1 year postpartum and to have decided against future pregnancies, as

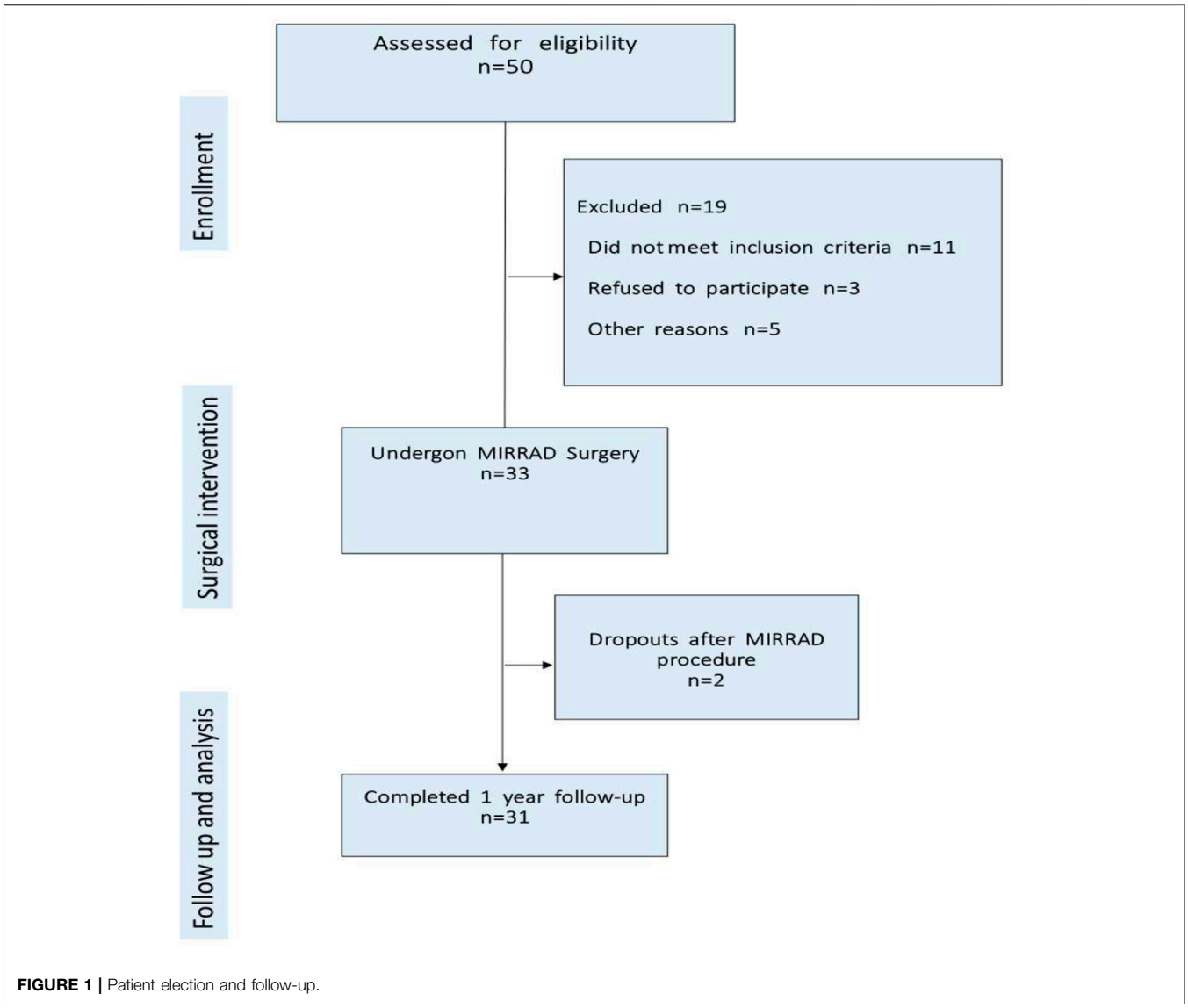

FIGURE 1 | Patient election and follow-up.

per the study criteria. All participants received comprehensive information about the study, both verbally and in writing.

A total of 50 patients were assessed for eligibility. Of these, 33 met the inclusion criteria and provided informed consent to participate in the study. A flowchart detailing patient selection, inclusion, exclusion, and follow-up is presented in **Figure 1**.

The primary outcomes assessed were improvements in physical health and overall life satisfaction.

Reasons for Exclusion

Out of 50 eligible patients assessed, 19 were excluded prior to surgery for reasons including not meet inclusion criteria (11), refusal to participate (3), seeking repairs elsewhere (3) and undergoing surgery elsewhere (2). Consequently, 33 patients underwent MIRRAD procedure. Two patients were excluded post-surgery, resulting in a final analysis of 31 patients.

Most patients were referred to the Hernia Center due to a diagnosed hernia or suspected hernia in the linea alba. All patients had at least one hernia, with the majority having hernias measuring ≤1 cm. Additionally, all patients presented with an inter-rectus distance (D2 H1) of at least 3 cm, with a mean width of 4.4 cm (SD ± 1.0 cm) (**Table 1**).

Each participant completed the Disability Rating Index (DRI), the Urogenital Distress Inventory-6 (UDI-6), and the Incontinence Impact Questionnaire-7 (IIQ-7) both before the surgery and 1 year postoperatively [12, 13]. Additionally, they underwent a Modified Abdominal Trunk Function Protocol (MATFP) assessment, conducted by a certified physiotherapist, both preoperatively and 1 year after the surgical repair [14]. Before surgery, participants were also provided with an accelerometer to monitor their physical activity levels.

TABLE 1 | European Hernia Society (EHS) classification of RD guidelines.

T (Type)	D (inter-rectus distance)	H (concomitant umbilical and/or epigastric hernia)
T1 = after pregnancy T2 = With adiposity	D1 = >2 cm D2 = >3–5 cm D3 = >5 cm	H0 = Without H1 = Present

MIRRAD Procedure

Minimally Incision Repair of Rectus Abdominis Diastasis (MIRRAD) surgery is a minimal incision procedure to plicate PP-RAD. The procedure is performed under general anaesthesia through a small skin incision near the umbilicus. It involves the plication of the rectus abdominis diastasis using barbed sutures as double-line suture, and if a concomitant hernia is found, it is sutured with 2.0 prolene before the plication. The umbilicus is then reattached to the fascia with single stitch of 4-0 PDS. The skin is closed with absorbable intradermal 3.0 Monocryl sutures, allowing for same-day discharge, which reduces hospital stay and cost **Figure 2**. All patients were provided an elastic abdominal binder before surgery and were advised to use it 6 weeks postoperatively. The hernia defects were repaired using non-absorbable sutures, while the rectus diastasis was closed with a 0-PDS double-lined barbed suture. All procedures were performed by the same experienced consultant surgeon at the Hernia Center, Region Örebro Län, Sweden. This repair method utilized an open surgical approach through a small skin incision near the umbilicus. While achieving similar results to the SCOLA method, the MIRRAD technique does not require mesh reinforcement. This method may serve as a bridge between traditional open surgeries and advanced laparoscopic techniques, offering a cost-effective and efficient solution for abdominal wall reconstruction. This technique is particularly appealing to patients seeking a less invasive option, delivering a balance between effective repair and a faster recovery.

Data Collection and Analysis

All women included in the study were aged between 20 and 50 years, with a BMI range of 18.8–30.1. None of the participants had undergone previous surgery involving the linea alba.

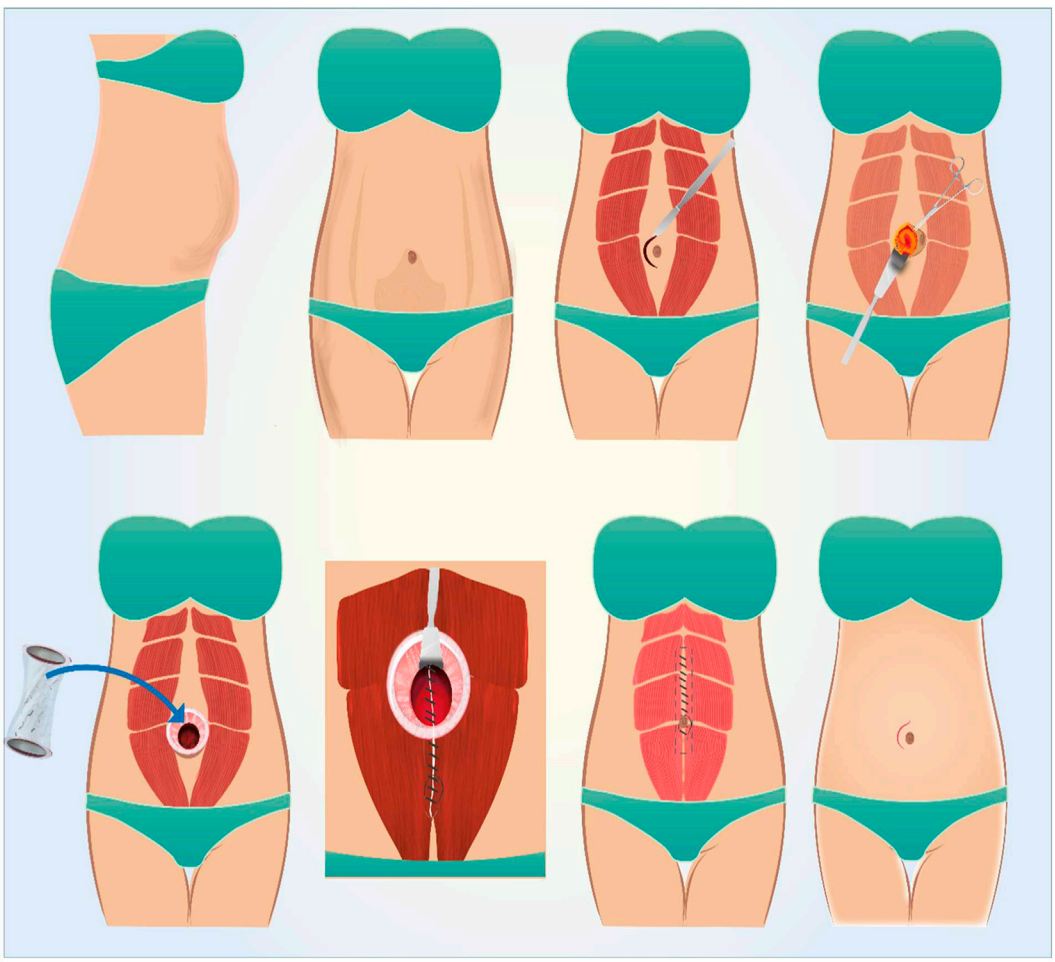

FIGURE 2 | Illustrating the MIRRAD repair procedure. Illust. from the author's library.

According to the study protocol, all women were enrolled at least 12 months after their most recent delivery and had decided not to pursue further pregnancies. Current illnesses (classified by ICD codes) and ongoing medications were recorded for all participants.

Data were collected electronically using Greenlight Guru Clinical (formerly Smart-trial) software. All data was stored according to the European data protection policy. Standardized assessments were conducted preoperatively and at 1 year postoperatively. An accelerometer is a device that measures acceleration forces in one or more directions, typically in three axes: X (horizontal), Y (vertical), and Z (depth). It detects changes in velocity over time, which can be used to measure motion, orientation, and vibration. It works by sensing motion through tiny sensors called MEMS (Micro-Electro-Mechanical Systems). These parts move when the device moves, generating an electrical signal that the device uses to calculate acceleration. The participants carried the device at all times while awake (except during showers and baths) for 5 days. After this period, they returned the device in a padded envelope to the principal researcher for computerised analysis. Each participant also kept a simple activity diary during this period with the accelerometer.

Physical Function and Strength Assessments

Modified Abdominal Trunk Function Protocol (MATFP): Conducted by a certified physiotherapist to evaluate abdominal wall strength and trunk stability.

Accelerometer Monitoring: Physical activity levels were measured using ActiGraph wGT3X-BT accelerometers over five consecutive days. Participants were instructed to wear the device during waking hours, except during bathing or swimming.

Questionnaires

Disability Rating Index (DRI): Assessed the impact of symptoms on daily activities.

Urogenital Distress Inventory-6 (UDI-6): Evaluated urinary symptoms.

Incontinence Impact Questionnaire-7 (IIQ-7): Measured the impact of urinary incontinence on quality of life.

Pain Assessment: Visual Analogue Scale (VAS): Used to measure postoperative pain at 4 h, 1 week, and 1 month after surgery.

Statistical Analysis

Data were exported to IBM SPSS Statistics version 29.0.0.0 for analysis. Continuous variables were expressed as mean ± standard deviation (SD) or median with interquartile range (IQR) as appropriate. The Wilcoxon signed-rank test was used to compare preoperative and postoperative outcomes. A p-value of <0.05 was considered statistically significant.

Ethical Considerations

The study was conducted in accordance with the Declaration of Helsinki and complied with the GDPR for data protection. All participants provided written informed consent after receiving detailed information about the study's purpose, procedures, and potential risks and benefits. The study was approved (Dnr. 2021-04599) by the Swedish Board of Ethics (Etikprövningsmyndigheten).

TABLE 2 | Accelerometer data summary using count per minute (CPM).

Type of physical activity (preoperative vs. postoperative)	Z	*P*-value
Light physical activity - preoperative vs. postoperative	–1.207	0.227
Moderate physical activity - preoperative vs. postoperative	–1.731	0.083
Vigorous physical activity - preoperative vs. postoperative	–2.352	0.019
Vector_Magnitude_CPM	–2.163	0.031
Steps Per Minute - preoperative vs. postoperative	–3.131	0.002

Wilcoxon Signed Rank Test. Based on positive rank.
Source: Katawazai et al., 2025.

TABLE 3 | DRI activity improvements pre- and 1-year post-operative.

Type of activity (Preoperative vs. postoperative)	Z	P-value
Dressing and undressing without assistance – Preop. Vs. postop.	–1.974[a]	<0.048
Walking – Preop. Vs. postop.	–3.466[a]	<0.001
Climbing stairs – Preop. Vs. postop.	–3.450[a]	<0.001
Sitting for an extended period – Preop. Vs. postop.	–3.798[a]	<0.001
Standing bent over a sink – Preop. Vs. postop.	–3.357[a]	<0.001
Carrying a bag or package – Preop. Vs. postop.	–4.023[a]	<0.001
Making a bed – Preop. Vs. postop.	–2.705[a]	<0.001
Running – Preop. Vs. postop.	–3.933[a]	<0.001
Physical work – Preop. Vs. postop.	–3.836[a]	<0.001
Strenuous physical work – Preop. Vs. postop.	–4.603[a]	<0.001
Exercise/sports – Preop. Vs. postop.	–4.389[a]	<0.001

Wilcoxon Signed Rank Test.
[a]*Based on positive rank.*
Source: Katawazai et al., 2025.

Recovery and Follow-Up

All study patients were followed up clinically by a surgeon and a physiotherapist 1 year after the procedure. Patients were encouraged to contact the clinic if they experienced any signs of complications. If any complications were suspected, the patient was invited for an additional visit, which included clinical examination, laboratory tests, or radiological assessment as necessary. All events related to the procedure were documented in Smart-trial, and additional visits were scheduled according to local protocols. Additionally, all patients were provided with an abdominal binder and advised to use it for 6 weeks postoperatively.

RESULTS

Patient Enrollment and Follow-Up

Out of 50 patients assessed, 33 met the inclusion criteria and were enrolled in the study. Two patients did not participate in the 1-year follow-up. One cited the long distance to the hospital, and the other provided no explanation. Both reported no complications at the 1-month postoperative follow-up. One-year follow-up data were successfully collected from the

TABLE 4 | UDI-6 and IIQ-7 results pre- and 1-year post-operation.

Type of activity/Symptom (Preoperative vs. postoperative)	Z	P-value
Need to go to the bathroom very often – Preop. Vs. postop.	−2.984[a]	0.003
Urinary leakage associated with a strong need to urinate – Preop. Vs. postop.	−2.357[a]	0.018
Urinary leakage associated with physical activity, coughing, or sneezing – Preop. Vs. postop.	−2.289[a]	0.022
Small amounts of urinary leakage (drops) – Preop. Vs. postop.	−3.000[a]	0.003
Postop._Difficulty emptying the bladder – Preop. Vs. postop.	−2.352[a]	0.019
Pain or discomfort in the lower abdomen or genital area – Preop. Vs. postop.	−2.951[a]	0.003
Postop._Ability to perform household chores (cooking, cleaning, laundry) – Preop. Vs. postop.	−1.732[a]	0.083
Postop._Leisure activities such as walking, swimming, or other physical activities – Preop. Vs. postop.	−3.957[a]	<0.001
Entertainment (e.g., movies, concerts) – Preop. Vs. postop.	−0.378[a]	0.705
Ability to travel by car or bus more than 30 min from home – Preop. Vs. postop.	−1.890[a]	0.059
Participation in social activities outside the home – Preop. Vs. postop.	−1.811[a]	0.070
Mental health (nervousness, depression, etc.) – Preop. Vs. postop.	−2.887[a]	0.004
I feel prevented from doing what I want – Preop. Vs. postop.	−3.106[a]	0.002

Wilcoxon Signed Rank Test.
[a]*Based on negative rank.*
Source: Katawazai et al., 2025.

TABLE 5 | MATFP results pre- and 1-year post-operation.

MATFP results (preoperative vs. postoperative)	Z	P-value
Back muscle strength (number of seconds) – Preop. Vs. postop.	−4.206[a]	<0.001
Abdominal muscle strength (number of seconds) – Preop. Vs. postop.	−4.321[a]	<0.001
Trunk stability in side-plank (Side plank) (seconds) – Preop. Vs. postop.	−3.991[a]	<0.001
Reached level – Preop. Vs. postop.	−3.328[a]	<0.001
Lifting right leg – Preop. Vs. postop.	−2.646[a]	0.008
Lifting left leg – Preop. Vs. postop.	−1.265[a]	0.206

Wilcoxon Signed Rank Test.
[a]*Based on positive rank.*
Source: Katawazai et al., 2025.

TABLE 6 | Patient satisfaction and discomfort scores.

	N	Minimum	Maximum	Mean	Std. Deviation
How satisfied is the patient with the operation?	31	2	10	8.6	1.7
How much discomfort has the patient experienced after the diastasis surgery?	31	1	6	2.3	1.3

Source: Katawazai et al., 2025.

31 participants who completed the study (**Figure 1**). Mean preoperative inter-rectus distance was 4.4 ± 1.0 cm. All participants were at least 1 year postpartum and had decided against future pregnancies. At the 1-year follow-up, no cases of hernia or rectus diastasis recurrence were reported. Two patients developed seromas, confirmed radiologically at 1 week and 1-month postoperative. Nausea was reported by five patients. No other surgery-related complications were observed. Postoperative pain was assessed using a Visual Analogue Scale (VAS), with mean pain scores of 2.8 at 4 h, 3.2 at 1 week, and 1.7 at 1 month following surgery.

The Wilcoxon signed rank test showed statistically significant improvements in physical activities, strength, and overall functional ability 1 year postoperatively compared to preoperative assessments. The analysis demonstrated significant enhancements in physical activities, strength, and overall ability. Notable reductions were recorded in urinary frequency, urinary leakage, and pain, alongside improvements in the ability to engage in leisure activities.

However, trends in household chores, travelling, and social activities did not reach statistical significance.

Accelerometer

Data were collected pre- and postoperatively to assess changes in physical activity. A Wilcoxon signed rank test revealed significant improvements in vigorous activities ($Z = -2.352$, $p = 0.019$), vector magnitude counts per minute ($Z = -2.163$, $p = 0.031$), and steps per minute ($Z = -3.131$, $p = 0.002$), indicating enhanced physical performance following surgery (**Table 2**).

Disability Rating Index (DRI)

The postoperative data showed significant improvements across all assessed activities. Dressing and undressing without assistance showed a statistically significant improvement ($p = 0.048$). Walking, climbing stairs, sitting for an extended period, standing bent over a sink, carrying a bag or package, making a bed, running, performing light physical work, performing strenuous physical work, and engaging in exercise or sports all demonstrated highly significant improvements, with Z values ranging from −2.705 to −4.603 and ($p- < 0.001$). Overall, the results show considerable improvements in physical abilities and daily activities 1 year after the procedure (**Table 3**).

Urogenital Distress Inventory-6, Incontinence Impact Questionnaire–7 (UDI-6, IIQ-7)

The postoperative results show significant improvements in several areas. There was a notable reduction in the frequency of urination

and in urinary urgency incontinence associated with physical activity, coughing, or sneezing. Minor leakage incidents also decreased significantly. Additionally, improvements were observed in difficulty emptying the bladder and in pain or discomfort in the lower abdomen or genital area.

Significant improvements were also seen in leisure activities and mental health, with a reduction in frustration levels. There were trends towards improvement in performing household chores, travelling, and participating in social activities, although these were not statistically significant (**Table 4**).

Modified Abdominal Trunk Function Protocol Assessment (MATFP)

The postoperative results showed significant improvements in muscle strength and trunk stability compared to the preoperative state. Both back and abdominal muscle strength increased significantly after the procedure, as did trunk stability in the side plank exercise. There were also notable improvements in overall levels reached in the assessment. Overall, these results indicate considerable gains in muscle strength and trunk stability following the procedure (**Table 5**).

Patient Satisfaction

All patients rated their satisfaction with their operation on a scale from 0 to 10 (out of 10), with a mean score of 8.65, indicating high satisfaction. Postoperative pain and discomfort levels were rated from 1 to 6 (out of 10), with an average of 2.32, suggesting low to moderate discomfort after surgery (**Table 6**).

Regarding abdominal wall stability 1-year post-surgery, 83.9% of patients reported feeling either quite better or much better, while only one patient reported no difference.

In summary, surgery resulted in high patient satisfaction, low postoperative pain and discomfort, and significant improvements in abdominal wall stability.

DISCUSSION

Summary of Findings

In conclusion, the MIRRAD procedure significantly improves physical strength, trunk stability, and urinary function in women with PP-RAD. One year postoperatively, participants showed significant enhancements in physical activities, reduced urinary symptoms, and improved quality of life.

Physical Function and Strength Improvements

The significant gains in back and abdominal muscle strength and trunk stability indicate the effectiveness of the MIRRAD procedure in restoring core muscle function. These improvements facilitated better performance in daily activities such as dressing, climbing stairs, and engaging in exercise, aligning with previous studies that highlight the benefits of surgical intervention for PP-RAD.

Urinary and Pain-Related Outcomes

The significant reduction in urinary frequency, urgency, and leakage suggests that repairing the rectus diastasis positively impacts pelvic floor function. Improvements in pain and discomfort, as well as better leisure activities and mental health, highlight the comprehensive benefits of MIRRAD procedure beyond mere physical strength.

Limitations and Strengths

This study has some limitations, the relatively small sample size of 31 patients may limit the generalizability of the findings. The lack of a control group prevents definitive conclusions about the procedure's efficacy compared to non-surgical interventions. A 1-year follow-up may not capture long-term outcomes and potential late-onset complications. Despite these constraints, the study's strengths include its prospective design and the use of validated outcome measures, which we believe add valuable insights into the treatment of rectus diastasis.

Future studies should include larger cohorts, control groups, and extended follow-up periods to validate these findings and assess the long-term effectiveness and safety of the MIRRAD procedure.

Conclusion

The MIRRAD surgical procedure is effective in improving physical strength, trunk stability, and urinary function in women with PP-RAD. The technique offers a minimally invasive option with minimal complications and significant improvements in quality of life. Despite the study's limitations, the findings contribute valuable insights and support the use of MIRRAD as a viable surgical intervention for PP-RAD.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author.

ETHICS STATEMENT

The studies involving humans were approved by Swedish Ethical Review Authority. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

AK wrote the study plan, which was approved by GS and GW. The study was conducted by the corresponding author and supervised by GS and GW. All study participants were examined before and 1 year after surgery using MATFP by AÄ. Data interpretation and analysis were performed by AK

and GS, with the manuscript reviewed by all authors. All authors contributed to the article and approved the submitted version.

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CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontierspartnerships.org/articles/10.3389/jaws.2024.13830/full#supplementary-material

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Gender Equality in Diastasis Rectus Abdominis in Chronic Back Pain: A Model of M. Transversus Abdominis Motor Control Impairment

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Introduction: Diastasis rectus abdominis (DRA) is defined as an increased distance between the left and right muscle of the m. rectus abdominis. Pregnancy-related factors are assumed to be dominant factors in the occurrence of DRA. However DRA is not only found in peri-partum women but also in men and nulliparous women with back or pelvic pain. This study provides an inventory of the incidence of DRA in subjects with chronic back and pelvic pain. If DRA is common in both men and women then other factors besides pregnancy, like impaired motor control, should be explored as cause for DRA.

Material and Methods: This study was conducted with data from 849 back pain patients. Results from ultrasound assessment of the abdominal wall were combined with anamnestic data on age, gender, medical history and pregnancies (in women).

Results: There was no difference in Inter Rectus Distance cranial of the umbilicus (IRD above umbilicus) between men and women. Almost half of all women and men (45% and 43%, respectively) exhibit an increased IRD above umbilicus. The incidence of an increased IRD above umbilicus is twice as high in women below 30 years, compared to men below 30 years old. This difference is not observed for men and women above 30 years old.

Discussion: DRA occurs in women during pregnancy and increases with an increasing number of pregnancies. However, this condition does not affect significantly more women than men. Increased IRD above umbilicus already occurs in young men (mean age 30). Over 30 years of age, cranial of the umbilicus there is no difference in IRD between women and men. An alternative etiological mechanism is suggested.

Keywords: diastasis recti, chronic pain, pregnancy, motor control, gender

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INTRODUCTION

Diastasis rectus abdominis (DRA) is defined as an increased distance between the left and right muscle of the m. rectus abdominis. It is assumed that the inter-rectus distance (IRD) increases due to widening or stretching) of the linea alba [1]. In addition, when intra-abdominal pressure (IAP) increases, bulging of the abdominal content through the linea alba can occur (**Figure 1**). This bulging can vary from marginal to substantial, with both aesthetic and functional consequences. In literature,

there is no consensus on conservative treatments for DRA [2, 3]. The results of surgical interventions for DRA also vary and hold significant risk for secondary incisional herniation [4, 5].

Conservative and operative interventions are performed despite uncertainty about the etiological mechanism behind DRA [6]. Since DRA is common in peripartum women, pregnancy-related factors have long been assumed to play a role in the development of DRA. [6], with a dominant notion being that pregnancy-related hormones weaken the linea alba, allowing it to stretch, consequently increasing the IRD.

The linea alba, the collagenous midline structure between both rectus muscles, is thick and strong, and its fibre structure is specifically fit for resisting lateral tensile force [7–10]. A recent study has shown that not only the linea alba but also the fascia (rectus sheath), that encloses the rectus muscles, in a transverse direction is very rigid [11]. Since the linea alba alone cannot be responsible for any potential increase in IRD, it is suggested that not just the linea alba but rather the abdominal wall as a whole stretches [12]. In addition, to this fact, DRA is found not only in peri-partum women but also in men and nulliparous women who suffer from back or pelvic pain [13].

It is assumed that DRA contributes to the development of back or pelvic pain [14–18]. However, there are indications that the aetiology is reversed: DRA does not cause back and pelvic pain; instead, low back or pelvic pain cause DRA. If this is the case, then a common denominator should be sought for the development of DRA both in pregnancy and in back and pelvic pain.

The purpose of this study is to make an inventory of the incidence of DRA in subjects with chronic back and pelvic pain. Based on common perceptions of DRA, it is hypothesised that the condition would be much more common in women in relation to pregnancy than in subjects with back and pelvic pain. If this is not the case, then the cause of DRA should no longer be sought in, for example, hormonal changes during pregnancy. Another etheological notion like a disturbed function of the trunk muscles is then more obvious. Such a disturbance in function has already been demonstrated in people with back or pelvic pain [19–22]. A question that subsequently arises is, to what extent can this disturbed or suppressed motor control be related to the development of DRA.

MATERIALS AND METHODS

In this retrospective study data were obtained from regular patient care, with written patient consent. Between 2019 and 2020, 849 patients were seen in a Dutch rehabilitation centre for the treatment of chronic back, pelvic or neck pain. Of those patients, 174 were excluded because they had predominantly neck problems ($n = 29$) or had incomplete data ($n = 145$). No other in- or exclusion criteria were applied. An ultrasound assessment of the abdominal wall was executed as an integral part of the diagnostic procedure. In addition, anamnestic data on the patients' medical history and pregnancies (in women) was recorded.

By means of ultrasound examination, both the structure of the abdominal wall and the function of the abdominal muscles (m. rectus abdominis, m. obliques externus and internus and m. transversus abdominis) were assessed. Sonography has proven to be useful for such evaluation [23]. The IRD was assessed at 5 cm cranial of (IRD above umbilicus) and 5 cm caudal of (IRD below umbilicus) the umbilicus (categories: 0–2 cm, 2–4 cm or >4 cm). While patients lay in a supine position and slightly lifted their head and shoulders, the amount of bulging was visually assessed 0 = no bulging, 1 = slight bulging, 2 = moderate bulging or 3 = substantial bulging.

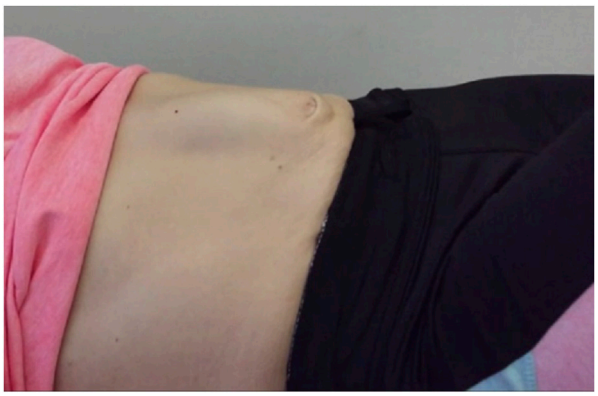

FIGURE 1 | Typical example of pain patient showing bulging and diastasis while performing an active straight leg raise.

Data Analysis

Data were analysed using Statgraphics Centurion version 18.1.16. The IRD above umbilicus and IRD below umbilicus and bulging were compared between selections from the population using the Kruskal-Wallis test. These selections were gender (male/female), age (≤30 years/>30 years) and pregnancy (0, 1, more than 1). Women who had never given birth and men were compared. The mean age of the group of nulliparous women was 30 years, and for comparison, the group of men was also selected with a mean age of 30 years. In addition, men with a mean age of 30 or younger were compared to men with a mean age older than 30. Furthermore, women with a mean age of 30 and younger were compared to women with a mean age over 30 years. The relationship between the degree of bulging and IRD was determined using the Spearmen rank correlation test, and p values less than 0.05 were considered significant.

RESULTS

Both male and female group had a normal distribution for age. No significant difference in age was observed between the male and female patient groups (**Table 1**). Overall, no difference in bulging or sonographically assessed IRD above umbilicus between men and women was found, although more women had an increased IRD below umbilicus. Notably 38% of both women and men, showed an IRD above umbilicus of 2–4 cm, leading to almost half of all women and men (45% and 43%,

TABLE 1 | Demographic data.

	Men	Woman all	Woman		
Pregnancies	n/a	n/a	0	1	>1
n	204	471	50	88	333
Mean age ±sd	43 ± 14	41 ± 14	30 ± 11	37 ± 10	45 ± 14
IRD Above umbilicus					
0–2	115	261	50	43	168
2–4	78	177	0	43	134
>4	11	33	0	2	31
IRD Below umbilicus					
0–2	199	420	50	76	294
2–4	5	47	0	12	35
>4	0	4	0	0	4

Note: The group of women was divided into nulliparous (0), uniparous (1) and multiparous (>1). Numbers are absolute values.

respectively) exhibiting an increased IRD above umbilicus (**Table 2**).

In the selection of nulliparous women (mean age 30 years), neither bulging nor increased IRD was found (**Table 3**). In the same age group of men however, bulging occurred in 9% of cases (7% slight, 2% moderate), and an increase in IRD above umbilicus occurred in 20% (18% 2–4 cm and 2% > 4 cm). These differences were all significant. Furthermore, IRD below umbilicus occurred in some men in this group (2%), but this was not significantly different from the nulliparous women.

When the number of pregnancies was considered, a clear impact of pregnancy was visible (**Table 4**). Between the nulliparous and single parous women, there was a significant increase in visible bulging (11% slight and 2% strong), and this effect continued with additional pregnancies. Moreover, 27% of the population with more than one pregnancy exhibited increased bulging (14% slight, 9% moderate and 4% strong). The IRD above umbilicus also increased in more than half of women after their first pregnancy. While the incidence of IRD above umbilicus did not increase much after additional pregnancies (from 51% to 57%), the severity of the IRD increased. With additional pregnancies, the percentage of women with an IRD above umbilicus >4 cm rose to 12%. By contrast, the IRD below umbilicus increased after the first delivery from 0% to 14% and the distribution altered with additional deliveries (2–4 cm in 13% and more than 4 cm in 2%).

Since the population included women younger than 30 who had been pregnant, groups were also compared for age, independent of pregnancy, in **Table 5**. In difference with the results in **Table 3**, the results in **Table 5** indicate bulging and an increase in IRD in women too, but no difference was found between women and men with a mean age of 30. After the men and women were divided into two groups: mean age 30 years vs. mean age >30 years, (not adjusted for pregnancies), the following results were observed. In both men and women, there was a significant increase in both bulging and IRD above umbilicus. While no difference in bulging was observed for men or women in the same age range, a difference in IRD above umbilicus existed between these groups, where women (37%, 2–4 cm and 3% > 4 cm) had an increased IRD above umbilicus twice as often as men (18%, 2–4 cm and 2% > 4 cm). For mean ages above 30 years old, there were still no differences in bulging between women and men. However, the group of men with an IRD above umbilicus of 2–4 cm was significantly larger than the group of women in the same age group. In all female groups, the IRD below umbilicus was more often larger than in men (9% and 12% in women and 2% and 3% in men).

Bulging was moderately, but significantly correlated with IRD above umbilicus but not with IRD below umbilicus. Moreover, IRD above umbilicus and IRD below umbilicus were also significantly correlated. Finally, the observed impairment of increasing IAP is related to increased bulging (**Table 6**).

DISCUSSION

The results of this study confirm the common assumption that DRA occurs in women during pregnancy. In the group of nulliparous women, neither bulging nor increased IRD was found (**Table 3**). However, after the first pregnancy, the incidence of bulging and increased IRD was far more pronounced (**Table 4**). It is interesting that bulging increases with an increasing number of pregnancies, while IRD above umbilicus and IRD below umbilicus increase predominantly in women who already suffer from this condition. However, there was no statistical difference between women and men.

In men (mean age 30 years) significantly more bulging and a larger IRD was observed when compared with nulliparous women (mean age 30 years).

This difference was not observed when these men were compared to all women with a mean age of 30 years. While bulging occurred to a similar extent, the increase in IRD was more pronounced in women than in men. This might indeed have lead to the assumption that pregnancy plays a role in the onset of DRA. However, based on the

TABLE 2 | Overall differences between males and females in bulging and in IRD above and below the umbilicus (all subjects).

	Bulging				IRD above umbilicus (cm)			IRD below umbilicus (cm)		
	no	slight	moderate	substantial	0–2	2–4	>4	0–2[a]	2–4[a]	>4
Male	80	10	7	3	56	38	5	98	2	0
Female	79	12	5	3	55	38	7	89	10	1

Notes: Values in %. Males, n = *204; Females,* n = *471. There was no significant difference between males and females for bulging and IRD, above umbilicus. Below umbilicus, the difference was significant (Kruskal–Wallis test,* p < *0.001), with a larger IRD.*

[a]*Occurring more often in women than in men.*

TABLE 3 | Overall differences in bulging and in IRD above and below the umbilicus between females (mean age 30 Years) without pregnancies (n = 50) and males in similar age group (n = 90).

	Bulging				IRD above umbilicus (cm)			IRD below umbilicus (cm)		
	no	slight[#]	moderate[#]	substantial	0–2	2–4[#]	>4[#]	0–2	2–4	>4
Male	91	7	2	0	80	18	2	98	2	0
Female	100	0	0	0	100	0	0	100	0	0

Notes: Values in %. There were significant differences between males and females for bulging and IRD, above umbilicus: ([#]) bulging and a larger IRD, occurred more often in men (p < 0.05 and p < 0.05). There was no significant difference in IRD, below the umbilicus between groups.

TABLE 4 | Differences in bulging and in IRD above and below the umbilicus between nulliparous, uniparous and multiparous women.

	Bulging				IRD above umbilicus (cm)			IRD below umbilicus (cm)		
Pregn	no[#]	slight[#]	moderate[#]	substantial[#]	0–2[#]	2–4[#]	>4[#]	0–2[#]	2–4[#]	>4[#]
0	100	0	0	0	100	0	0	100	0	0
1	87	11	0	2	49	49	2	86	14	0
>1	73	14	9	4	43	45	12	85	13	2

Notes: Values in %. There was no significant increase from nulli- (n = 50) to uniparous (n = 88) women or from uni-to multiparous (n = 261) women. There was a significant increase in all parameters between nulli- and multiparous women (Kruskal–Wallis test, p < 0.001).

TABLE 5 | Overall differences in bulging and in IRD above and below the umbilicus between males and females.

	Bulging				IRD above umbilicus (cm)			IRD below umbilicus (cm)		
	no	slight	mod	subs	0–2	2–4	>4	0–2	2–4	>4
Men ≤30	91	7	2	0[a,b,c]	80	18	2[d,e,f]	98	2	0[g,h]
Women ≤30	86	10	3	1[b,c]	61	37	3[e,f]	91	9	0
Men >30	71	12	11	6[c]	38	54	8[f]	97	3	0[h]
Women >30	74	14	7	4	51	38	10	87	10	2

Notes: Values in %. Males: mean age ≤30, n = 90; mean age >30, n = 115. Females: mean age ≤30, n = 210; mean age >30, n = 261. p-value <0.05 are considered significant. Mod = moderate, subs = substantial.

[a]Bulging is significantly different from woman ≤30.

[b]Bulging is significantly different from men >30.

[c]Bulging is significantly different from woman >30.

[d]IRD, above umbilicus is significantly different from woman ≤30.

[e]IRD, above umbilicus is significantly different from men >30.

[f]IRD, above umbilicus is significantly different from woman >30.

[g]IRD, below umbilicus is significantly different from woman ≤30.

[h]IRD, below umbilicus is significantly different from woman >30.

TABLE 6 | Correlations between bulging, IRD above and IRD below the umbilicus.

Variables	Correlation	*p*
Bulging vs. IRD Above	0.40	0.0000[#]
Bulging vs. IRD Below	0.29	0.2936
IRD Above vs. IRD Below	0.37	0.0000[#]

Notes: Sample size n = 675. p values < 0.05 are considered significant. ([#]).

results in men above 30 years of age, some confusing observations were made.

Firstly, bulging is found to be similar in men and women in the same age group (**Table 5**). Secondly, an increase in IRD above umbilicus occurs more often in men than in women (62% vs. 49%).

Third, for IRD above umbilicus, there is no difference in the level of increased IRD, and IRD below umbilicus occurs only slightly more often in women than in men.

This analysis confirms the notion that pregnancy is a trigger for the onset of DRA. The question, however, is whether pregnancy itself is the aetiological factor. The finding that men in this study were similarly affected by DRA calls for reconsideration of the underlying mechanism for the emergence of DRA. The following question arises: could there be a general mechanism affecting both women during pregnancy and men. And even more interestingly: could there be a relation with suffering from low back and/or pelvic pain?

Typical of this study population is that all subjects suffer long-lasting back or pelvic pain. For the past decades, much attention has been paid to the role and function of transversus abdominis (TrA) in relation to back and pelvic pain [24, 25]. TrA is involved in multiple tasks. Aside from providing stability to the spine TrA contributes to breathing and to regulating IAP [11, 22, 26]. In relation to IAP, a main task of TrA is to tension the posterior abdominal

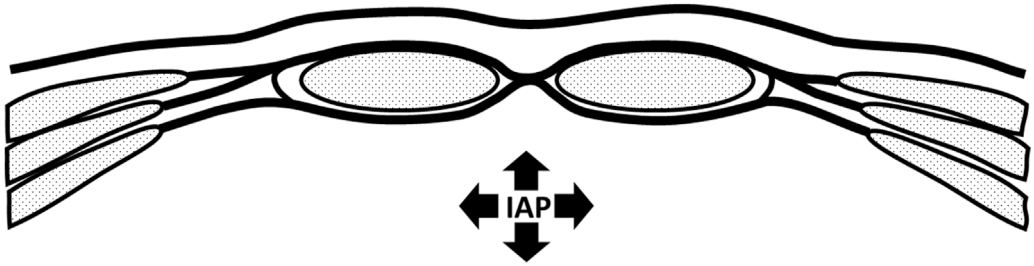

FIGURE 2 | Schematic representation of abdominal wall. No contraction and low intra abdominal pressure.

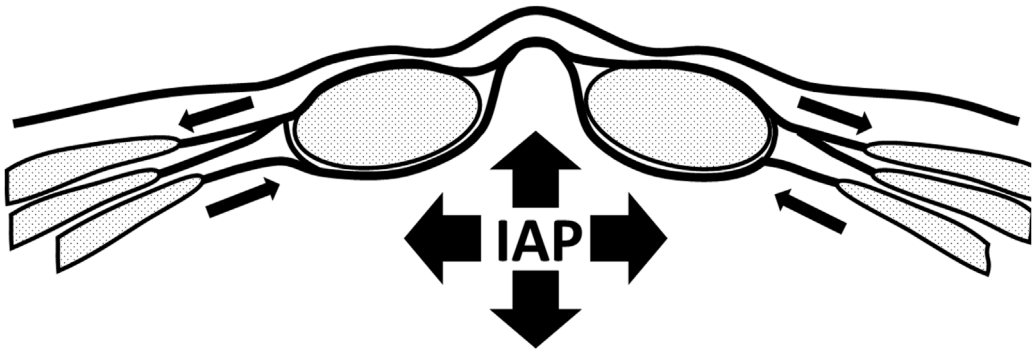

FIGURE 3 | Abdominal with activation of rectus abdominis, for example, when performing a curl-up exercise. Intra abdominal pressure increases. Contraction of m. transversus abdominis is impaired, leading to bulging and increase on intra rectus distance.

fascia sheath, including the dorsal rectus fascia and linea alba (**Figure 2**).

IAP is normally increased by co-contraction of the diaphragm, pelvic floor and abdominal wall [22, 26]. With impaired TrA function, as found in back or pelvic pain patients, contribution to the increase in IAP will be limited. Contraction of the diaphragm and pelvic floor will increase IAP to some extent. However, the abdominal wall will show bulging because TrA insufficiently tensions the posterior layer of the ventral abdominal wall (e.g., the posterior rectus fascia). The abdominal content will consequently be pressed outward between both rectus muscles, separating the muscle bellies and consequently increasing the inter rectus distance (IRD). Frequent repetition of this mechanism over an extended period of time may lead to structural separation of the bellies of the rectus abdominis, increased IRD, and elevated IAP. As a consequence, bulging in the area of the linea alba will then become visible.

A similar mechanism can be found in pregnant women. A growing embryo requires increasing abdominal space during pregnancy [27, 28]. It is suggested that this volume is created by stretching of the abdominal wall, especially the passive fascial tissue. Pregnancy-related hormones can increase the (temporal) slackening of connective tissue [29]. However, the question remains as to whether stretching of the passive tissues of the abdominal wall meets the spatial requirements and, moreover, whether the stretching of fascia tissue meets this spatial requirement at the right pace. An immediate way to create more space in the abdominal cavity is by relaxing the abdominal muscles, hence using the specific properties of muscle tissue [12]. Particularly TrA, due to its connection with the posterior rectus fascia and linea alba, will be included in this mechanism.

Here, a common mechanism may be identified in: (a) back and pelvic pain and (b) pregnancy In both circumstances there might be neuromuscular suppression of TrA activity. And in both situations, the effect on abdominal wall behaviour is similar, leading to an increase in IRD (**Figure 3**).

In this study, no control group without low back or pelvic pain was included. Furthermore, the excluded group of neck patients was too small for analysis. Analysis over time of the occurrence of and increase in bulging and IRD may provide additional information on this mechanism. Additionally, despite the rather large cohort, the group size was still relatively small. It can be expected that some women in the group up to 30 years of age without pregnancy would exhibit bulging and an increased IRD. This was not found in the present study, probably due to the limited group size. In this study, only age, gender and pregnancy were included. Other factors, such as trauma (physical impact), congenital diastasis, BMI or abdominal surgery (including caesarean section) are confounding or even etiological factors for the occurrence of DRA. Regrettably these data could not be included in the present study. It is suggested that such factors are included in future studies.

Nevertheless, we have to be aware that surgical interventions aiming at solving DRA, may contribute to diminished TrA

activation and consequently deterioration of abdominal wall function.

CONCLUSION

The aim of this study was to make in inventory of the incidence of DRA in subjects with chronic back and pelvic pain. It is found that pregnancy plays a role in the occurrence of DRA in women. However, with increasing age, there is no difference in the occurrence of DRA in women or men with chronic back or pelvic pain. This leads to the assumption that not pregnancy itself but rather an underlying mechanism similar to pregnancy and low back and pelvic pain plays a role in the occurrence of DRA. It is postulated that suppression of activation of TrA may contribute to the onset and aggravation of DRA. From this perspective, conservative measures including restoration of motor control of the abdominal wall muscles (especially the transversus abdominis muscles) can be applied before considering surgical interventions for DRA.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

Ethical approval was not required for the study involving humans in accordance with the local legislation and institutional requirements. Written informed consent to participate in this study was not required from the participants or the participants' legal guardians/next of kin in accordance with the national legislation and the institutional requirements. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

J-PW: Concept writing, data analysis statistics. IR: Writing, data gathering, statistics G-JK: concept, writing, interpretation of data. All authors contributed to the article and approved the submitted version.

CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Some Additional Data That Might Be Useful for Diastasis Recti Assessment

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Background: Diastasis recti (DR) is characterized by separation of both rectus muscles and protrusion of the median bulging, but besides median bulging DR can also entail global abdominal bulging. On other note, DR classification is based on the width of divarication, but measurement values are different at rest and at effort due to muscle contraction. Aim of the study is to provide additional features concerning the type of bulging and the width of divarication.

Methods: Findings were retrospectively drawn from the data prospectively collected in the records of a continuous cohort of 105 patients (89 females, 16 males) referred for diastasis and concomitant ventral hernia repair.

Results: There was a median bulging alone in 45 (42.9%) cases, a global bulging alone in 18 (17.1%) cases, both types combined in 37 (35.2%) cases and no bulging in 5 (4.8%). On 55 patients with a global bulging, 51 were females. Tape measurements values of DR width were closer to the values measured on the CT scan at leg raise than at rest. The differences were significant at rest as well as at leg raise. Though the difference at rest was highly significant ($p = 0.000$), the difference at effort was not far from being not significant ($p = 0.049$).

Conclusion: Besides median bulging, presence or absence of the global bulging should be included in DR assessment. The difference between width of divarication at rest and on exertion raises the question of which value should be used for DR classification. The question is worth being debated.

Keywords: diastasis recti, medial bulging, global bulging, width of divarication, diastasis recti classification

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INTRODUCTION

According to the European Hernia Society (EHS) guidelines on management of diastasis recti (DR), the latter is defined as an inter-rectus distance (IRD) exceeding 2 cm, and it is classified D1 for IRD ≥2–3 cm, D2 for IRD ≥3–5 cm and D3 for IRD ≥5 cm (1).

In most cases DR predominates at the supra and peri-umbilical parts of abdominal wall because the linea alba is in the shape of a tuning fork. Depending on the lengthwise extension, DR can be divided in three main features: supra-umbilical, supra and peri-umbilical, and supra and infra-umbilical.

Width of the divarication can be assessed by clinical examination using a tape or a caliper, as well as by ultrasound or CT scan or even MRI. According to EHS guidelines, measurement of IRD using either ultrasound or calipers is a reliable method, but there is no clear answer as to whether IRD should be measured at rest or during active muscle contraction. Since most papers providing IRD values do not specify the conditions of measuring, it is likely that they are tacitly measured at rest.

FIGURE 1 | Medial bulging **(A)**, global bulging **(B)** and postoperative result **(C)** in the same patient.

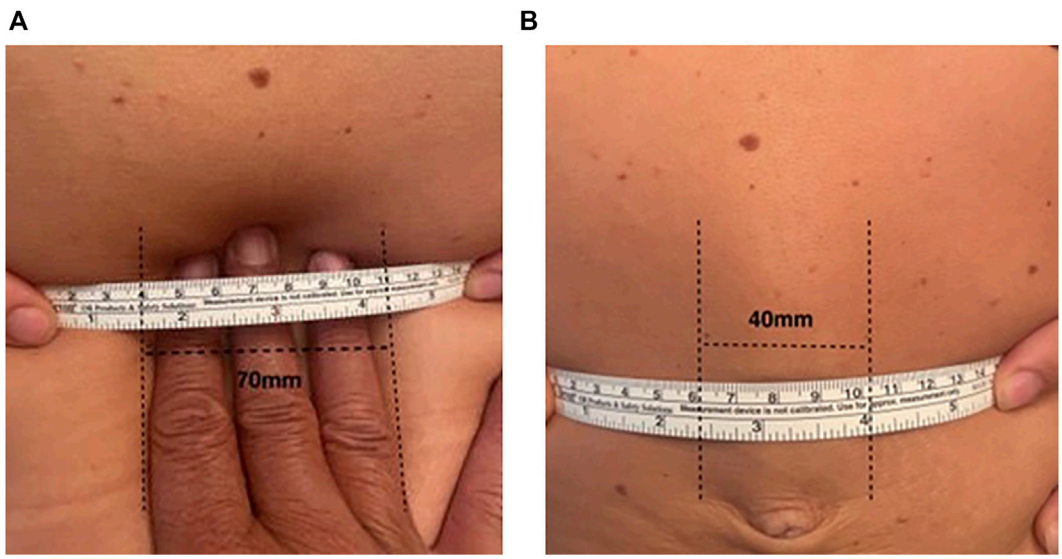

FIGURE 2 | Measuring the width of divarication with a tape at rest **(A)** and at straight leg raise **(B)**.

However, IRD values differ depending on whether the muscles are contracted or not, since muscle contraction tends to approximate the muscle borders. Furthermore, the daily practice shows that besides the median bulging, DR can also entail global bulging of the abdominal wall, which can affect the patient's body image (**Figure 1**).

Aim of the study is to provide some additional features concerning measurement of the width of divarication and the type of bulging, drawn from the data that were systematically and prospectively collected on a continuous cohort of patients referred to our institute for diastasis and ventral hernia repair.

PATIENTS AND METHODS

Data on patient demographics, as well as diastasis and hernia characteristics, are prospectively recorded in our database, with the patient consent, for every patient referred to our institute for surgery. The study is based on the retrospective review of the records.

IRB advice was not requested because all patients referred to our institution are informed that data are anonymously collected for evaluation, and the study was based on data only, not on persons or on surgical practice.

In patients with DR, it is our current practice to record the presence or not of the medial bulging, the width of divarication by measuring the distance between the medial borders of both rectus muscles with a tape measure on the supine patient, 2–3 cm above the navel, at rest as well as at straight leg-raise (**Figure 2**). Similarly, the presence or not of the global bulging, defined as global enlargement of the abdomen, based on visual examination of the patient in the upright position at rest, is recorded. When a CT scan is performed the radiologist records the distance between the

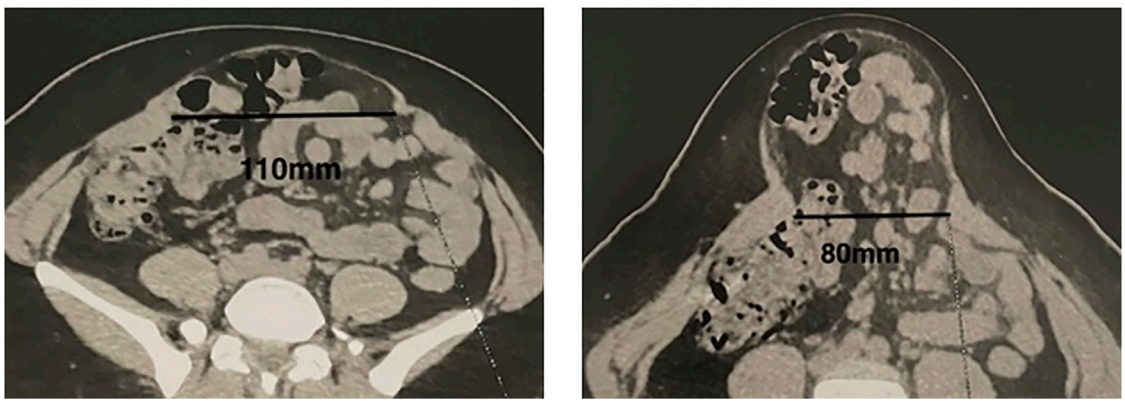

FIGURE 3 | Measuring the width of divarication on the CT scan at rest **(A)** and at straight leg raise **(B)**.

TABLE 1 | Patient demographics and diastasis characteristics.

Patients n	**105**
Males n (%)	16 (15.2)
Females n (%)	89 (84.8)
Age median (range)	40 (18–82)
BMI median (range)	21.54 (16.9–39.8)
Parous women n (%)	83 (79)
Diastasis	
Supra umbilical n (%)	23 (21.9)
Supra and peri-umbilical n (%)	47 (44.8)
Supra and infra-umbilical n (%)	35 (33.3)
Medial bulging alone n (%)	45 (42.9)
Global bulging alone n (%)	18 (17.1)
Both types n (%)	37 (35.2)
No bulging at all n (%)	5 (4.8)
Ventral hernias n (%)	103 (98.1)

TABLE 2 | Divarication width at rest and at leg-raise, with tape measure and CT scan.

	Tape measure	**CT scan**	**p***
At rest (mm) mean, SD	71.5, 23.04	46.7, 13.99	0.000
Leg-raise (mm) mean, SD	35.3, 12.03	39.8, 12.79	0.049

**Student T test for paired samples.*

TABLE 3 | Width of diastasis according to EHS classification (1) at rest vs. at leg raise.

	Rest	**Leg-raise**
D1 ≥ 2–3 cm	0	13
D2 ≥ 3–5 cm	46	82
D3 ≥ 5 cm	59	10

medial borders of both rectus muscles at L4 level at rest and at straight leg raise (**Figure 3**).

Comparison of values of the divarication width at rest, obtained by tape measuring *versus* CT scan, and same comparison of values obtained at straight leg raise, were carried out using the Student T test for paired samples, on 40 cases for which clinical data as well as CT scan measurements were fully documented.

RESULTS

The results are given in **Tables 1**–**3**. The cohort involved 105 patients, 89 females and 16 males, who were operated from January 2020 to August 2022; 83 of the 71 females were parous. The type of DR was supra-umbilical in 23 (21.9%) cases, supra and peri-umbilical in 47 (44.8%) cases and supra and infra-umbilical in 35 (33.3%) cases. There was a median bulging alone in 45 (42.9%) cases and a global bulging alone in 18 (17.1%) cases. Both types were present in 37 (35.2%) cases and in 5 (4.8%) cases there was no bulging at all. On 55 patients with a global bulging, 51 were females and only four were males. A ventral hernia was present in 103 (98.1%) cases (86 umbilical, 5 epigastric, 10 combined, and 2 incisional).

Table 2 shows that the differences between diastasis width measured with a tape or on the CT scan were significant at rest as well as at leg raise. Nevertheless, when the difference at rest was highly significant ($p = 0.000$), the difference at effort was not far from being not significant ($p = 0.049$).

Moreover, **Figure 4A** shows that the values obtained by tape measuring at rest are notably divergent from the dashed line and tend to overestimate the tape measurement compared to CT scan, when **Figure 4B** shows that values obtained by tape measuring at leg raise are close to the dashed line and homogeneously distributed on either side of the line.

These results suggest that the results obtained by tape measurement are closer to the values measured on the CT scan at leg raise than at rest.

Table 3 shows that the type of diastasis according to EHS classification would be different, depending on whether measurements are taken at rest or at leg raise.

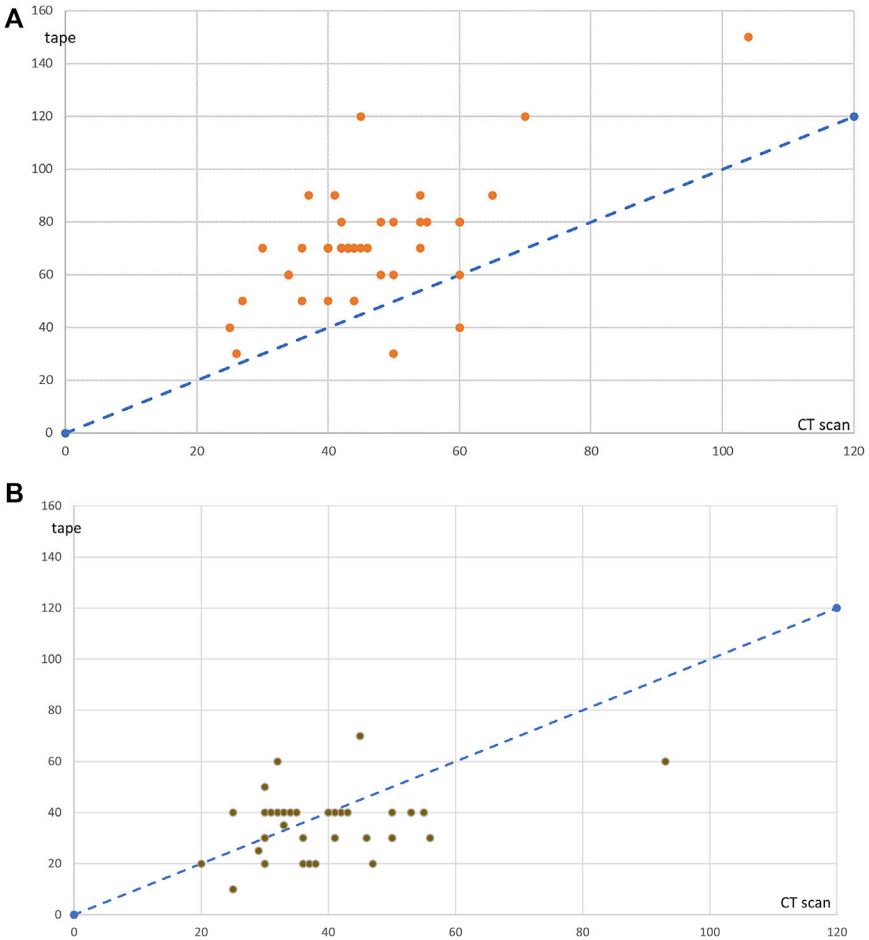

FIGURE 4 | Values measured on the CT scan (x-axis) or with the tape (y-axis) for each of 40 cases, at rest **(A)** and at leg raise **(B)**. The dashed line represents the ideal position of values if tape measurements and values measured on the CT scan were identical.

DISCUSSION

The results highlight two main points: on one hand the median bulging was present in only 78% of the cases (47 alone and 37 combined), the global bulging was present in 52% of the cases (18 alone and 37 combined) and both were combined in 35% of the cases; on the other hand the distance between the medial borders of both rectus muscles was different at rest and at straight leg-raise and depending on whether it was measured on the patient with a ruler or on the CT scan.

The median bulging is commonly regarded as an essential characteristic of DR (2). However, in our series, the median bulging was present in only 78% of the cases, there was no bulging at all in 4.8%, and the global bulging, defined as global enlargement of the abdomen, based on the patient's complaint and on visual examination of the patient in the upright position (**Figure 1**), was present in half the cases. The medial bulging is well known but the global bulging is less commonly mentioned in publications, although it can affect the patient's body image. It is more frequent in women (51 females on 55 cases) who say, "it is as if I were pregnant". The diagnosis of global bulging is based on visual examination of the patient in the standing position at rest, thus we suggest that examining the patient standing as well as in the lying position, be part of diastasis assessment. Measuring the waist circumference just above iliac crests might help bulging evaluation and comparison between preoperative and postoperative status. Unfortunately, we did not include this measurement in our database. Nevertheless, we suggest that measuring the waist circumference is worth being part of the checking and from now we include it in our database.

Concerning the width of divarication, the values collected at clinical examination by tape measuring and the values measured on the CT scan, were close at leg-raise, but at rest they were larger at clinical examination than on the CT scan. As a matter of fact, the difference was highly significant at rest (p = 0.000), but the difference at leg-raise was not far from being not significant (p = 0.049), as shown in **Table 2**. Moreover, **Figure 4A** shows that the values obtained by tape measuring at rest tend to overestimate the width of

divarication compared to CT scan, when **Figure 4B** shows that the values obtained by tape measuring at leg raise are close to the values measured on the CT scan.

Differences between IRD values measured at manual examination or by imaging methods have been reported by others (3–6). However, it is difficult to know which method provides the most accurate evaluation.

According to Emanuelsson et al the CT scan underestimates IRD in comparison with tape measure at clinical examination as well as intraoperatively (3). On the contrary, Mughal and Ross consider that the right value is provided by CT scan or ultrasound (4). In the study by Nahas et al there was no difference between the values measured on the CT scan and intraoperatively (5). Chiarello et al compared IRD values measured by caliper to ultrasound at rest as well as on exertion (curl-up), they found no significant difference between both methods above the umbilicus, when IRD values measured by caliper were higher than the values measured by ultrasound below umbilicus, what suggests that in this location it is manual examination that overestimates IRD (6).

In our study comparing tape measure to CT scan at rest and at leg-raise, IRD values at rest were higher at tape measure than on the CT scan, when there was no difference between both methods at leg-raise.

Based on the above, it is difficult to conclude which is the best method to objectively assess IRD. Some explanations of these discrepancies have been suggested.

Emanuelsson et al (3) suggested two possible explanations: one is that during scanning the patients tend to involuntarily contract their abdominal muscles, what is plausible. The other one is that the CT scan identifies the most medially located muscular fibers "even though they have no relevance," but these medial fibers are actual muscular fibers that participate to the suturing repair, and there is no reason to consider that they are negligible.

It may also be that identification of the medial bounds of rectus muscles is less precise at manual measurement, due to subcutaneous tissue thickness, as suggested by Chiarello et al. (6).

Ultrasound, which is commonly used in current practice (1, 7, 8), might be the best method, provided it is performed by an experienced operator, because it allows dynamic imaging: by talking to the patient the operator can obtain muscle relaxation as well as contraction.

If we admit that CT scan images correspond well to anatomy, our results showing that values provided by tape measurements are closer to values measured on the CT scan at leg raise than at rest, suggest that measurements on exertion should be taken in consideration.

Given the ambiguity as to the best method of IRD measurement, some other studies comparing tape measurement, caliper, intraoperative, ultrasound and CT scan, are worth being carried out.

Table 3 shows that the type of diastasis according to EHS guidelines classification (1) would be different, depending on whether measurements are taken at rest or at leg raise, whereas correct categorization of the cases has practical significance. This finding raises the question of which value should be taken in consideration for diastasis classification, namely at rest or on exertion, or both. In current practice the CT scan is indeed not routinely performed. In most cases the classification is based on clinical measurements, and classifying the cases makes practical sense, since the width of divarication can influence the choice of surgical technique.

As a matter of fact, Bellido Luque et al. (9) suggest that a diastasis greater than 6–7 cm of separation could benefit from the use of a reinforcement patch rather than a simple suture because of excessive tension on the suture line, but they do not specify if this statement is based on measurements taken at rest or on exertion. Based on our clinical experience, though not on evidence-based data, we consider that tension on the suture line is excessive when IRD is superior to 6 cm on exertion. On the contrary when IRD is superior to 6 cm at rest, the laxity of aponeurotic structures allows tension-free approximation suture of rectus muscles.

The principal strength of this study is that it is based on data which were systematically and prospectively recorded for every patient referred for the repair of ventral hernia combined with DR and that it draws attention on two issues that are not commonly addressed: 1) should the global bulging be included in DR assessment? 2) should IRD measured at rest, or on exertion, or both, be taken in consideration?

The main weakness is that CT scan measurements were available in 40 cases only, since they were not performed systematically in every case, and that some data are missing, such as measurement of the waist circumference in patients who had a global bulging, back pain evaluation, quality of life and body image assessment by questionnaires.

CONCLUSION

Besides the median bulging, presence or absence of the global bulging should be included in DR assessment. Global bulging should be assessed by visual examination on the standing patient at rest, and ideally completed by measurement of the waist circumference just above iliac crests.

Besides measurement of the width of divarication at rest, measurement on exertion (leg-raise or curl-up) should be taken in consideration. The difference between measurements taken at rest and on exertion raises the question of which value should be used for diastasis classification. The question is worth being debated.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

Data on patient demographics, as well as diastasis and hernia characteristics, are prospectively recorded in our database, with the patient consent, for every patient referred to our institute for surgery. The study is based on the retrospective review of the records. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

PN, J-PC, and SG carried out surgery. PN, J-PC, and EP performed study conception, data collection and redaction. DB carried out statistics.

CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Reference Data on the Normal Abdominal Wall Anatomy and Baseline Characteristics in Seventy-One Nulliparous Women

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Aims: The aim of this study was to describe the prepartum anatomy of the abdominal wall in a cohort of nulliparous women, for use as a reference for management of patients with postpartum abdominal wall insufficiency with or without rectus diastasis.

Materials and Methods: Seventy-one women were examined with ultrasonography of the abdominal wall. The inter-recti distance (IRD), anatomical variations of the linea semilunaris, and the oblique muscles were assessed. The waistline was measured during activation and relaxation of the abdominal core. Participant characteristics were registered. Questionnaires regarding habitual physical activity (Baecke), low back pain (Oswestry), physical functioning (DRI), urinary incontinence (UDI-6 and IIQ-7), and quality-of-life (SF-36) were answered.

Results: Mean age was 30.5 years (range 19–50 years) and mean BMI 23.5 kg/m^2 (range 18–37). Ultrasonography showed a mean IRD of 10 mm (range 3–24) at the superior border of the umbilicus, 9 mm (4–20) 3 cm above the umbilicus, and 2 mm (–5–10) 2 cm below the umbilicus. The mean thickness of the linea alba was 3 mm (1.5–5) and mean distances between the lateral edge of the rectus muscle and the external, internal, and transverse oblique muscles were 12 mm (–10–28), 1 mm (–14–13) and 15 mm (–14–32) at umbilicus level. Responses to the DRI, UDI-6, IIQ-7 and Oswestry questionnaires showed generally lower scores than the normal population whereas Baecke and SF-36 scores were similar.

Conclusion: This study provides baseline data on normal abdominal wall anatomy in a healthy nulliparous female cohort, as well as levels of activity, physical function, disability, and quality-of-life.

Keywords: pregnancy, diastasis recti abdominis, rectus diastasis, linea alba, postpartum

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INTRODUCTION

The abdominal wall supports stability and motion of the trunk and protects the abdominal viscera. The anatomy of the abdominal wall is affected by pregnancy, obesity, and other conditions that stretch and widen the muscles, fasciae, and skin. One important component of these abdominal wall deformations is widening of the linea alba, i.e., rectus diastasis (RD) (1).

The development of RD is a normal physiological anatomical change during pregnancy caused by mechanical stretching of the abdominal wall combined with hormonal changes (2). Approximately one-third of postpartum women are reported to have a persistent RD following pregnancy (3). RD has traditionally been defined as an inter-recti distance of 2.8–3 cm, based on a few studies (4, 5). In recent guidelines issued by the European Hernia Society (EHS), RD is defined as a separation of the rectus abdominis muscles exceeding 2 cm (6).

As research continues, our understanding of the structural and mechanical properties of the muscles and fasciae of the abdominal ventral wall has increased. Several studies describe the inter-recti distance (IRD) at different stages postpartum. Available research on nulliparous women have reported mean inter-recti distances in a range of 13–18 mm. Beer et al. assessed 150 nulliparous women with ultrasound in a supine position and measured the IRD at three different points (5). Balasch-Bernat et al. included 75 women, of whom 25 were nulliparous, in their measurement of the IRD (7). Tuominen et al. compared the IRD in nulliparous, with postpartum women (8). In Stecco's measurement of the thickness of the abdominal muscles and fasciae, a total of 36 women were included of whom 13 were nulliparous (9, 10). The architecture of collagen fibres in the linea alba and rectus sheath is well described by Axer et al. in a study on 12 human cadavers (11).

Previous anatomical studies have thus focused on the linea alba, measuring the width and thickness of this fascial connection. The linea alba is well described in the literature but information is sparse on the normal anatomy and postpartum changes of muscles and fasciae in other regions of the abdominal wall such as the linea semilunaris. Linea semilunaris is the fascial connection between the medial aspect of the external oblique, the internal oblique and the transversus abdominis muscles connecting respectively to the lateral aspect of the rectus abdominis muscle. There are no reference values presented on this fascial connection in the literature although it may also be affected by the stretching forces during pregnancy.

All reported values of the linea alba, both clinically and during surgery, have been obtained in the supine position, which differ from most activities in everyday life, mainly performed in the upright standing or sitting position. From a biomechanical perspective, forces acting on the abdominal wall differ between these body positions. In the present study we therefore examine the RD in both supine lying as well as in standing to examine if the RD changes with body position in nulliparous women. We intend to define baseline values of the abdominal wall anatomy, to compare with measurements on postpartum women. To completely understand how the abdominal wall copes with RD, measures in relaxed supine position as well as during straining are needed.

The natural course from nulliparous state to the postpartum period is poorly described in previous studies and few studies have followed the natural course longitudinally. There is thus a need for studies with normative anatomic measures for nulliparous as well as multiparous women. Studies have shown an association between structural changes of the abdominal wall and both physical performance and functional disability (12). We need to understand postpartum anatomical changes in relation to functional demands, but there are no standardized data on normal physical function levels in the nulliparous population.

The main reasons for carrying out surgery for RD is, in addition to cosmetic improvement, to improve abdominal trunk function. More studies on the effectiveness of surgery for restoring continence and trunk function are needed. Such studies should be based on baseline data from women prior to surgery as well as nulliparous women in order to assess the actual benefit from the treatment. Ideally, randomized controlled trials may provide data on what RD surgery may accomplish in comparison with the outcome from conservative management. There is, however, a need for normative studies assessing the trunk function in nulliparous as well as multiparous women to fully understand how the symptoms change as the result of a pregnancy as well as from surgery aiming at restoring the function.

The aim of the present observational study was to increase our understanding of the normal abdominal wall anatomy in nulliparous women, before hormonal and structural changes appear during pregnancy. This study measures and systematically describes the normal anatomy of the abdominal wall and describes baseline functional levels in nulliparous women. Using these baseline values, we aim to compare nulliparous with postpartum women, intended to provide anatomical and functional references for decision-making prior to surgical reconstruction of the abdominal wall.

METHODS

Seventy-one healthy nulliparous female volunteers were recruited *via* social media, including Instagram and Facebook. The invitation to participate was widely spread among users, both private users as well as professional users, clinics and companies. The information was spread to different social groups and age groups in Stockholm and Sweden. Physiotherapy clinics also spread the information at their clinics in different parts of Stockholm, by putting up flyers.

The inclusion criteria were nulliparous healthy women aged 18–50 years, who had never been at any stage of pregnancy. Women who had previously undergone abdominal surgery through midline incision were excluded, but women who had undergone laparoscopic surgery or open surgery though incisions not involving the midline were considered eligible. Clinical examinations and questionnaire completion were performed at the clinic Hela Kvinnans Klinik in Stockholm. The duration of the appointment was approximately 30 min;

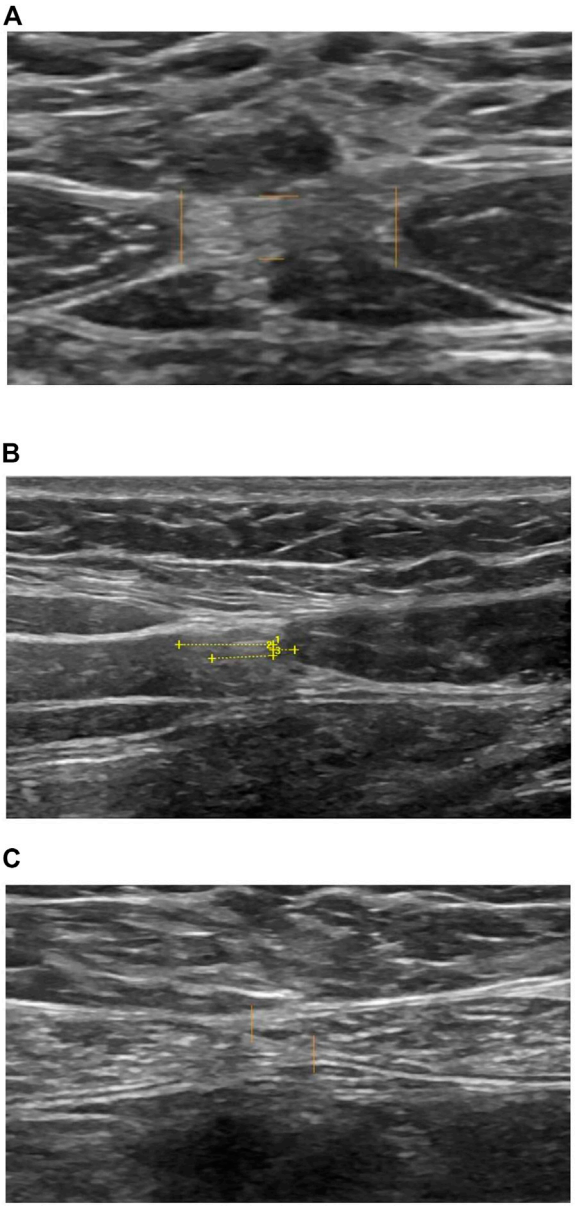

FIGURE 1 | Ultrasound measurement. **(A)** Lina alba IRD and thickness. **(B)** Linea semilunaris at umbilical level. 1) Rectus abdominis muscle to external oblique muscle. 2) Rectus abdominis muscle to internal oblique muscle. 3) Rectus abdominis muscle to transverse abdominis muscle. **(C)** Linea alba 2 cm inferior to umbilicus, IRD negative value.

ultrasound examination 20 min and questionnaire completion 10 min.

Ultrasound Assessment

The General Electric ultrasound machine Logiq® P9 with high resolution 50 mm linear array transducer was used. Eight ultrasound images were taken at five different locations, and in two body positions. Two exercises were filmed with the ultrasound at one location in supine lying. Three different measurements were taken with a tape measure at one location, in two different body positions. The examination was performed in both supine as well as in standing position to examine if the RD changes with body position.

All ultrasound examinations were conducted in a standard setting at the same clinic, and by one operator (KW) with 5 years' ultrasound experience and more than five hundred hours of documented ultrasound musculoskeletal imaging (KW). The focus and depth of the ultrasound signal were adjusted to the individual depending on the anatomy, and automatic time gain control and cross beam were used. The same machine settings were used and remained as standard throughout all examinations.

Anatomical Preferences

Linea Alba

The separation of the medial borders of the rectus muscles were measured 3 cm superior to the umbilicus, just above the superior margin of the umbilicus, and 2 cm inferior to the umbilicus. Point zero was set at the outer margin of the umbilicus cavity. The linea alba measurements were performed at the same locations described by Beer et al. (5) and Lee et al. (13). A senior radiologist (CH) defined the most medial aspect of the muscular compartment of the rectus abdominis muscle from where measurements were performed. In cases where the muscular compartment was poorly defined at the point of measurement, we followed the innermost aspects of the posterior and anterior rectus sheaths to identify the medial confluence (**Figure 1A**).

Linea Semilunaris

There are currently no recommended locations and methods for the measurement of linea semilunaris, so we used the lateral border of the rectus muscle on the right at the level of the umbilicus and at the inferior margin of the costal arch on the right to document normal anatomical variations. The aim of this measurement was to determine the position of the lateral border of rectus abdominis in relation to the medial borders of the external oblique muscle the internal oblique muscle, and the transverse abdominis muscle where they fuse into the linea semilunaris.

Point zero was set at the most lateral aspect of the muscular compartment of rectus abdominis muscle, measuring the lateral distance to the most medial aspect of the muscular compartment of the external oblique muscle, the internal oblique muscle, and the transverse abdominis muscle respectively (**Figure 1B**).

In cases where the muscular compartment was poorly defined at the location of the measurement, we followed the curvatures of the innermost aspects of the posterior and anterior rectus sheaths respectively to find their lateral or medial confluence depending on the muscle examined. All standards were set in agreement with the radiologist. In one case the three examiners were not able to reach agreement as the ultrasound images did not provide the necessary information at that location. These images were excluded. The anatomical findings are described in **Table 1**. Measurement locations are shown in **Figure 2**.

The ultrasound images of the linea alba and linea semilunaris were taken in the supine position with the head on a small pillow, the legs fully extended, the muscles of the abdominal wall fully relaxed during normal breathing, and the arms resting beside the body. The ultrasound film clips were taken in the supine position

TABLE 1 | Anatomical findings with Ultrasound and tape measurement assessment. Inter-recti distance (IRD) at different levels in supine and standing positions; linea semilunaris width at umbilicus level and coastal arch level, specified on the distance between the lateral lining of the rectus abdominis (RA), the medial lining of the external oblique (EO), the internal oblique (IO) and the transverse abdominis (TrA) muscles; waist circumference tape measurements at different levels.

Ultrasound imaging supine	**Mean (mm)**	**Range (mm)**
IRD 3 cm above the umbilicus	9	4–20
IRD at the superior border of the umbilicus	10	3–24
IRD 2 cm below the umbilicus	2	−5–10
Thickness of the linea alba	3	1.5–5
Linea semilunaris width at umbilicus level		
Distance between the RA and the EO	12	−10–28
Distance between the RA and the IO	1	−14–13
Distance between the RA and the TrA	15	−14–32
Linea semilunaris width at coastal arch level		
Distance between the RA and the EO	9	−11–24
Distance between the RA and the IO	1	−9–16
Distance between the RA and the TrA	−10	−33–25
Ultrasound imaging standing		
IRD at the superior border of the umbilicus standing relaxed	12	3–26
IRD at the superior border of the umbilicus standing on one leg	13	6–37
Waist circumference tape measurements	Mean (cm)	Range (cm)
Hip bones supine relaxed	85	71–119
Hip bones standing relaxed	89	76–125
Hip bones standing on one leg	87	71–122

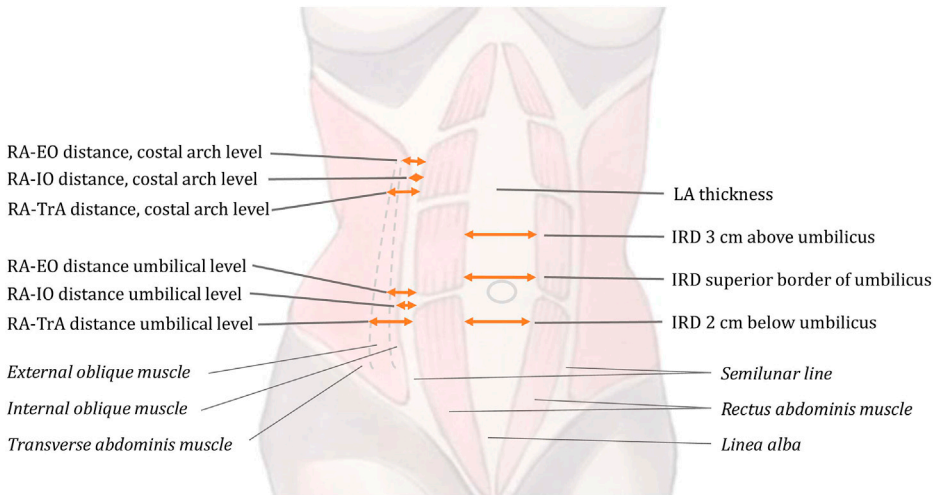

FIGURE 2 | Description of the anatomical measurement points. The inter-recti distance (IRD) measured at three positions: superior border of the umbilicus; 3 cm above and 2 cm below the umbilicus. The thickness of linea alba (LA) measured above the umbilicus. Variations of the linea semilunaris anatomy are described with measurements of the distance between the lateral lining of the rectus abdominis (RA); the external oblique (EO); the internal oblique (IO); and the transverse abdominis (TA) muscles at the umbilicus level and at the coastal arch level.

with the legs bent 90° at the knee joint and the spine flat with neutral lordosis.

The spontaneous curl-up was performed by asking the woman to look at her knees by raising her head and curling up the shoulders. The curl-up was interrupted when the therapist could place his hand beneath the woman with the fifth finger along the table and the first and second fingers touching the spinous process of the woman's first thoracic vertebra. This generally occurred when the spines of the scapula were lifted from the bench. This movement was performed without further instructions. The preactivated curl-up was performed by instructing the woman to gently activate the pelvic floor and the abdominal wall muscles, breathe out, and then perform the curl-up as described above.

While standing relaxed, the woman was told to shift to a comfortable stance with the feet hip width apart, to take a deep breath, and then fully relax the abdominal wall muscles. The breathing was repeated until the woman seemed to stand fully relaxed. When balancing on one leg, the woman was asked to lift

TABLE 2 | Study population characteristics.

Mean age, years (standard deviation) range	30.5 (6.0) 19–50
Mean BMI (standard deviation) range	24 (3.4) 18–37
Type of living	
Living single	27 (38%)
Living with partner/engaged/married	41 (58%)
Living with parents/other adult	3 (4%)
Level of education	
Primary and high school education	11 (16%)
University education or similar	45 (63%)
Higher academic level	15 (21%)
Occupation	
Sedentary	16 (23%)
Intermediate	50 (70%)
Heavy	5 (7%)

Occupation, description of the levels. Sedentary: e.g., administrator, IT developer, accountant (Baecke work score <2); Intermediate: e.g., nurse, physiotherapist, midwife, naprapath, pharmacist (Baecke work score ≥2 to ≤4); Heavy: e.g., personal trainer, nurse w lifting, dancer (Baecke work score >4).

the other knee up to hip level and keep her balance. No preactivation or relaxation of the abdominal wall was done.

The anonymized ultrasound images were reviewed by the manual therapist (KW) performing all measurements, and a specialist surgeon (AO), both with more than 5 years' experience of ultrasound imaging and interpretation. All images were also reviewed by a radiologist (CH) with more than 15 years' experience.

Waist Circumference Measurements

The circumference of the abdominal wall was measured at the hip bones, at the cristae iliaca, and at the widest point of the lower abdomen (generally 2 cm below the umbilicus). The tape measure was applied directly to the skin at each location in three different positions (supine position, standing with relaxed abdominal wall, and standing on one leg) to assess any measurement difference.

In the supine position a small pillow was placed under the head, legs fully extended, abdominal muscles fully relaxed, with normal breathing and arms resting beside the body.

In standing relaxed position, the woman was instructed to stand with a comfortable stance with the feet about hip width apart, to take a deep breath, and then to fully relax the abdominal wall muscles. The breathing was repeated until fully relaxed.

While standing on one leg, the other knee was raised to hip level keeping balance. No preactivation or relaxation of the abdominal wall were done.

Questionnaires

To determine functional levels and link these with the results of ultrasound, participants completed questionnaires regarding urinary incontinence (UDI 6, IIQ 7) (14), low back pain (15), disability rating in everyday life (DRI) (16), habitual physical activity (Baecke) (17), and a general questionnaire of lifestyle and health (SF-36) (18).

Statistical Analysis

Statistical analyses were carried out using SPSS 28.0. Differences between the SF-36 subscale ratings and the predicted ratings from the age-matched female background population was tested with paired t-test. The association between BMI, waist circumference and IRD were tested with Pearson's correlation test. The sample size was determined based on assumptions regarding the variability in the population.

RESULTS

Mean age was 30.5 years (range 19–50 years) and mean BMI 24 kg/m^2 (18–37). Study population characteristics are shown in **Table 2**. Ultrasonography showed a mean IRD of 10 mm (3–24) at the superior border of the umbilicus, 9 mm (4–20) 3 cm above the umbilicus, and 2 mm (−5–10) 2 cm below the umbilicus. Mean thickness of the linea alba was 3 mm (1.5–5). Mean distances between the lateral edge of the rectus muscle and the external oblique, internal oblique, and transverse muscles were 12 mm (−10–28), 1 mm (−14–13), and 15 mm (−14–32) respectively at the level of the umbilicus.

IRD at the superior border of the umbilicus in relaxed standing position was 12 mm (3–26) and standing on one leg 13 mm (6–37).

We did not find any statistically significant correlation between waist circumference and IRD, neither in supine position, standing relaxed or standing on one leg. There was also no correlation between BMI or any of the IRD measures. Circumference of the abdominal wall in the supine position, standing relaxed, and standing on one leg was 85 cm (71–119), 89 cm (76–125), and 87 cm (71–122) respectively.

Responses to the questionnaires showed generally low scores for DRI, UDI-6, IIQ-7, and Oswestry, and generally high scores for the Baecke questionnaire (**Table 3**). The women rated their physical function ($p < 0.001$) and bodily pain ($p < 0.001$) higher than the age-matched background population, but vitality ($p = 0.004$), role emotional ($p = 0.001$) and mental health ($p < 0.001$) lower than the background population (**Figure 3**).

DISCUSSION

Postpartum abdominal wall insufficiency has gained increasing attention as a condition amenable to surgical treatment or appropriate training. However, a full understanding of the

TABLE 3 | Questionnaires and symptom scores from the questionnaires, Baecke, oswestry, disability rating index, urinary distress inventory and the incontinency impact questionnaire.

	Mean (SD)	Range
Baecke		
Occupational physical activity	2.84 (0.80)	1.375–4.25
Sports physical activity	3.18 (1–06)	1–5.00
Leisure time physical activity	3.11 (0.64)	1.75–4.50
Oswestry (low back pain)	1.75 (3.00)	0–13
Disability Rating Index (DRI)	4.09 (6.22)	0–26.92
Urinary Distress Inventory (UDI 6)	1.80 (2.47)	0–11
Incontinence Impact Questionnaire (IIQ7)	0.28 (0.90)	0–5

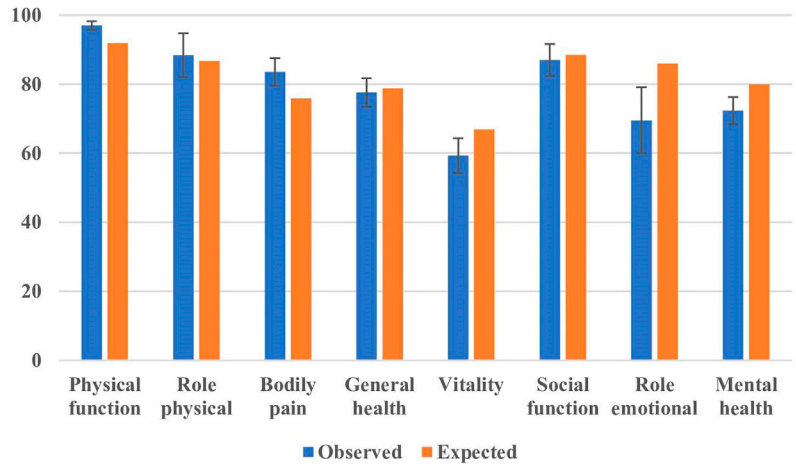

FIGURE 3 | SF-36 outcome. Error bars indicate 95% confidence interval. The expected outcome was determined from an age-matched cohort of women.

impact of pregnancy on the anatomy and physiology of the abdominal wall can only be achieved when it is related to prepartum anatomy and function. The present data are derived from a cohort of seventy-one Swedish nulliparous women whose abdominal wall anatomy was examined in detail using ultrasound. The findings in this study provide several well-defined anatomical measurement points that can be used for reference values.

The level of physical activity was in general moderate to high in comparison with previous reports (19). The nulliparous women in this study rated their physical health slightly higher than the normal population, but their mental and emotional status slightly lower (**Figure 3**).

Most women had few or no urinary symptoms, but a small group of outliers had several symptoms, accounting for the broad range of ratings. The majority did not suffer from lower back pain or abdominal wall insufficiency. Of the participants in our study, 38 women (54%) were above the mean age of first pregnancy in Sweden.

Not only pregnancy but also age affects the anatomy and function of the abdominal wall. Some women were well over the age of 30, but none was postmenopausal. The aim of the study, however, was to investigate a broad range of fertile nulliparous women, including those who had passed the age when most women have already undergone their first delivery. This could explain why the ratings on some of the subscales of SF-36 deviated from the background population.

There are anatomical differences between individuals that might have affected the results. This is especially true regarding the location 3 cm superior to the umbilicus, where the fascia of the tendinous intersection of the rectus abdominis is located in some individuals, with a low density of muscle fibers. In these individuals it is more difficult to find the exact measurement locations for IRD as described above. In other individuals, the muscle belly of the rectus abdominis muscle is well developed at this location, and measurement is easy. This caveat applies to all studies measuring the linea alba at different locations, not only ours.

The points zero for RD measurements were set at the same anatomical points described by Beer et al. and Lee et al. (5, 13). Our findings support the new classification system suggested in the EHS guidelines from 2021 (6), where RD is defined as a separation of the rectus abdominis muscles exceeding 2 cm. In our study only one participant had an IRD exceeding 2 cm at the superior border of the umbilicus in the supine position.

We found no description of locations or methods for measurement of the linea semilunaris in the literature. We chose to locate measurements lateral to the umbilicus on the right side and inferior to the costal arch on the right side. The reason for choosing these locations is the presence of clear anatomical landmarks for reference purposes, though we are aware that the costal arch position against the spinal column can differ between individuals. We decided to measure at these locations because this provides important information when performing rectus diastasis surgery.

The advantage of ultrasonography is the possibility to measure both anatomy and muscle activity in different body positions. However, it is operator-dependent and requires adequate training. Studies have confirmed good inter-rater reliability indicating that ultrasound imaging is a reliable instrument for evaluating abdominal muscle and fascial thickness (20, 21). A complementary ultrasound examination is a feasible and valuable method that can be recommended for use in everyday clinical practice (22).

Ultrasound measurement of the abdominal wall anatomy showed lower IRD values than previous comparable findings (5) (**Table 1**). IRD in the supine position was 10 mm measured at the superior border of the umbilicus. When measuring the IRD 2 cm inferior to the umbilicus, we found negative values in six participants. This was because the rectus muscles overlapped at the assessed location. In 17 participants there was no separation between the rectus abdominis muscles 2 cm inferior to the umbilicus. Our findings gave a mean of 2 mm 2 cm inferior to the umbilicus, which differs from the widely accepted value of 16 mm or more when defining RD at this location.

Mean IRD when standing with the abdominal wall relaxed was 12 mm (3–26 mm) at the level of the umbilicus, which is wider than the median value in the supine position (10 mm). However, in 18 participants (25%), IRD was ≥1 mm less when standing relaxed compared to the supine position. The range of IRD in the standing position could be the result of posture, the extent to which the abdominal wall was relaxed, pain while standing, and other possibilities. Participants were not given instructions on the standing posture, only instructions on how to relax the abdominal wall. These results could serve as baseline references when comparing nulliparous women with postpartum women. No other study comparing these body positions could be found.

The mean IRD when standing balanced on one leg was 13 mm (6–37 mm) at the level of the umbilicus which is wider than mean values when supine (10 mm) and standing with relaxed abdominal wall (12 mm). However, in 14 participants (19%), IRD was ≥1 mm less when standing on one leg compared to standing relaxed. The difference in readings could be due to the lack of instruction on the standing posture. The participants were instructed to stand on one leg and lift the other knee up to hip level.

Narrowing of the IRD could possibly be caused by the combined forces of all muscle layers of the abdominal wall when standing on one leg, including the deep transverse muscle, both layers of the oblique muscles as well as the rectus abdominis muscle. The rectus abdominis muscle probably narrows the IRD. We cannot comment whether this narrowing of the IRD is the result of natural contraction together with the other deeper abdominal muscles, or if it is a result of excessive contraction of the rectus abdominis muscle itself. We did not register standing posture or compensations made to maintain balance; factors that will be investigated in a future study.

The anatomy of the semilunaris varied at both locations. A contributing factor to this could be individual variation in location of the umbilicus in relation to the costal arch. In future studies, perhaps the measurement locations should be related to levels in the vertebral column for better uniformity. Other measurement points could also be considered.

In this study we included measurement of the abdominal wall circumference with a tape measure. This is an important measurement and correlates to general health and is usually measured at the level of the hip bones (23). We used the measurement at the hip bones, usually 2 cm below the umbilical level, where the abdominal circumference usually is widest. This is due to get reference values for the nullipara group to have as baseline values to the postpartum group of women. Some participants found it difficult to fully relax the abdominal wall, especially in the standing position. Having a higher resting tone in the abdominal wall and the rectus abdominis muscles may affect the width of the linea alba (13, 23) as well as the abdominal wall circumference.

This study will be followed up by a single-blinded training study on women 3–12 months postpartum. The measurements from this observational study may provide baseline values for nulliparous women for comparison with postpartum women. They may also serve as baseline data on the anatomy of the abdominal wall in general and the linea alba specifically in nulliparous women. Although there are several possible locations to measure the linea alba, the measurement points used in this study have been used in previous studies (4, 5), are reproducible, and provide values that can be related to those derived from the other study groups.

If RD is to be considered a pathologic condition requiring surgical correction, a baseline state of the unaffected abdominal wall anatomy has to be defined. Surgery may be indicated also for symptoms presenting during the course of what may be considered a normal adaptation to pregnancies, but this may affect priorities and resource allocations. To be able to define any deviation from the normal anatomy in the postpartum period, reliable measures of the anatomy in nulliparous women are crucial.

Limitations

Although the aim was to identify a group of women that represented the entire Swedish nulliparous population, there may have been selection bias in the recruitment process. Although it was a convenience sample, there may have been a selection of active women with expectations and demands on their functional level. Nevertheless, the questionnaire results indicate that the sample did not deviate substantially from the general population. As social media was the base for recruitment, women actively seeking information related to their own health may have been over-represented.

The age range (19–50 years) may question the external validity of the study since the mean age of first pregnancy in Sweden in 2021 was 30.1 years (24). Of all Swedish women, 13.5% were still nulliparous at the age of 45 in 2020 (25). The size of the sample was relatively small, which may limit the external validity of the study. Nevertheless, the standard intervals presented in **Table 2** were relatively narrow, which indicates that a larger sample would not have substantially changed the outcome. On the other hand, a sample mixture that more accurately would have reflected the entire female nulliparous population may have provided other outcomes.

We chose waist circumference as a measure of truncal obesity as we believe this to be a more appropriate measure than weight or Body Mass Index (BMI). It is, however, possible that inclusion criteria based on BMI could have provided a cohort that would have reflected women considered for surgical management of RD in a hypothetical postpartum stage more adequately.

CONCLUSION

The present data and measurement points may serve as a standard for assessing linea alba and linea semilunaris in women. More studies are needed to evaluate their clinical relevance and how they are affected by pregnancy.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Ethical Review Board of Stockholm (Dnr. 2020-02804). The patients/participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

The study was designed by KW, AO, and GS. Recruitment, examinations and registration was performed by KW. Interpretation of US results was performed by KW, AO, and CH. Statistical analyses was performed by GS. The article was written by KW with contribution from AO, GS, and CH. All authors contributed to the article and approved the submitted version.

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CONFLICT OF INTEREST

KW is cofounder of and works for Hela Kvinnans Klinik and Stockholm Hernia Center. AO is founder of and employed by Stockholm Hernia Center. CH is employed by the Company Unilabs Radiology.

The remaining author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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An Algorithmic Approach for the MIS Repair of Ventral Midline Hernias Associated With Diastasis of the Rectus Abdominis Muscle

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Purpose: We present our algorithmic approach for symptomatic ventral hernias with Diastasis of the Rectus Abdominis Muscle (DRAM).

Methods: Retrospective analysis of patients with symptomatic ventral hernias and DRAM undergoing hernia repair and plication of DRAM from July 2018–March 2021 was conducted. Based on our algorithm, patients were selected for an Endoscopic Onlay Repair (ENDOR) or a Robotic Extended Totally Extraperitoneal Ventral Repair (R-eTEP).

Results: We performed a R-eTEP in fifty-seven patients and an ENDOR in twenty-four patients. In the R-eTEP group, thirty-seven (65%) patients were female, the mean age was 54.8 (±10.6), and the mean BMI was 32 (±4.8). Fifty patients (87.7%) had multiple defects, of which 19 (38%) were recurrent hernias and 31 (62%) were incisional hernias. The mean operative time was 200 (±62.4) minutes, with two cases requiring a hybrid approach. The median length of stay was 1 day (0–12), and the median follow-up was 103 days. Twenty-four patients underwent an ENDOR, 19 females (79.2%), the mean age was 45.7 years (±11.7) and the mean BMI was 28 (±3.6). 13 patients had isolated umbilical or epigastric hernias. The mean operative time was 146.2 min (±51.1). Fibrin sealant and suture was the predominant method for mesh fixation, and most cases were performed in an ambulatory setting. Four patients developed post-operative seromas; one requiring drainage due to infection. The Median follow-up was 48.5 days (10–523), with two reported hernia recurrences.

Conclusion: An algorithmic approach for adequate patient selection was shown to be safe for treating ventral hernias with DRAM.

Keywords: robotic abdominal wall repair, ventral hernia repair, laparoscopic ventral hernia repair, minimally invasive, diastasis of the rectus abdominis muscle

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Abbreviations: DRAM, diastasis of the rectus abdominis muscle; ENDOR, endoscopic onlay repair; R-eTEP, robotic extended totally extraperitoneal ventral repair; BMI, body mass index; VHR, ventral hernia repair; IRB, institution review board; HIPPA, The Health Insurance Portability and Accountability Act; IR, institution review; DM, Diabetes Mellitus; COPD, Hypertension, Chronic obstructive pulmonary disease; CVA, cerebrovascular accident; ASA, American Society of Anesthesiologists; LOS, length of stay; SSO, surgical site occurrences; MIS, minimally invasive surgery; CO_2, carbon dioxide; LUQ, left upper quadrant; LLQ, left lower quadrant; IPOM, intraperitoneal onlay mesh.

INTRODUCTION

Diastasis of the Rectus Abdominus Muscle (DRAM) is a common abnormality due to increased abdominal pressures and or weakening of the linea alba resulting in a widening of the inter-rectus distance [1–3]. It is most commonly seen in females, obese patients, and individuals with prior abdominal surgeries [2–5]. The resulting midline bulge is associated with a negative body image, musculoskeletal pain, and occasionally urogynecological symptoms [3, 5].

Ventral hernias and concomitant symptomatic or asymptomatic DRAM are common. An untreated DRAM at the time of a ventral hernia repair has been associated with a higher risk of recurrence after ventral hernia repairs (VHR) [4, 6–8]. Therefore, we have tailored our approach based on the hypothesis that repairing an associated diastasis during a VHR may lead to a lower recurrence rate. The surgical management of ventral hernias is heterogeneous. The best location of the mesh and the surgical approach is still controversial.[9] Open, laparoscopic, and robotic approaches have been described in the literature.[9] However, the appropriate patient selection for the different operative approaches to treat this entity remains a subject of debate [10, 11].

The aim of this study is to present our algorithmic approach and early results for the treatment of symptomatic small ventral hernias with concomitant DRAM.

METHODS

Study Design

This is a descriptive, retrospective study of consecutive patients with symptomatic ventral hernias and DRAM undergoing hernia repair and plication of the diastasis from July 2018–March 2021. Data were obtained from electronic health records from a single academic medical center. This study was approved by the Institution Review Board number (IRB # 2020-11160) and all Health Insurance Portability and Accountability Act (HIPPA) compliant mechanisms were followed.

Inclusion Criteria

Adult male and female patients >18 years of age with a symptomatic single or multiple ventral hernias (<5 cm in size) undergoing elective minimally invasive VHR with an associated symptomatic or asymptomatic DRAM (Diastasis >2 cm as defined by the European Hernia Society, diagnosed clinically or *via* Computed Tomography).

Exclusion Criteria

Patients <18 years of age, pregnant patients, emergency surgery, presence of a parastomal hernia, hernia size >5 cm, open surgery.

Data Collection

Institutional Review Board approval was obtained to conduct this study. Data were retrospectively collected from a prospective database and divided into four sections: patient characteristics, Hernia characteristics, perioperative data, and patient outcomes. Patient demographics and comorbidities were analyzed: age, sex, body mass index (BMI), Diabetes Mellitus (DM), Hypertension, Chronic obstructive pulmonary disease (COPD), smoking status, Stroke, Cardiovascular accident (CVA), previous myocardial infarction, and American Society of Anesthesiologists (ASA) class. We did not collect data from open surgery as our objective was to show the early results of our minimally invasive procedures.

Preoperative data in the setting of incisional or recurrent hernias included Swiss cheese defects, type of primary hernia and or presence of multiple hernia defects.

Intraoperative and postoperative data consisted of the type of the approach, fixation of the mesh, duration of the surgery, length of stay (LOS), complications, readmissions, and follow-up.

Statistical Analysis

Descriptive analysis was performed. Categorical variables are expressed as counts and percentages. Continuous variables were reported as mean and standard deviation for continuous variables whose distribution approximated normality and median and range for those with skewed distributions. Chi-square and Fisher's Exact tests were used for categorical variables. T-tests and Wilcoxon rank-sum tests were used for continuous variables.

Anatomy and Definition

Diastasis recti manifest as a midline abdominal bulge due to an attenuated linea alba with an increased laxity of the ventral abdominal wall musculature [1–3]. Anatomically, the linea alba's width ranges from 11 to 21 mm between the xiphoid process and the umbilicus and decreases from 11 to 2 mm from the umbilicus to the pubic symphysis [5]. The thickness of the linea alba decreases towards the pubic symphysis; however, the posterior sheath is slightly thicker above the umbilicus compared to the anterior sheath [5]. The definition of DRAM varies in the literature, commonly defined as the distance from the muscular borders in the midline ranging from 2.2 to 3 cm above the umbilicus in a relaxed state, and can be classified as mild (<3 cm), moderate (3–5 cm), and severe (>5 cm) [7, 12]. Other classification systems such as the Nahas and Beer classification (which are based on the myofascial deformity, etiology, and the normal width of the linea alba in nulliparous women) have been utilized in the literature [5]. Most recently in 2021, the European Hernia Society (EHS) defined a rectus diastasis as a widening of the linea alba exceeding 2 cm and proposed a classification based on the width of muscle separation, post pregnancy status, and whether or not there is a concomitant hernia.[13].

Indications for Surgery

The most common indication for surgical intervention in patients with DRAM is discomfort and cosmesis [5, 14]. There is not clear evidence that the presence of symptomatic or asymptomatic DRAM at the time of a ventral hernia repair is a risk factor for recurrence when left untreated, but in our institution it is part of our algorithmic approach [4, 6–8].

Treatment Algorithm

Different options for treating midline hernias with symptomatic or asymptomatic DRAM exist, including non-operative management with core strengthening, aerobic activity, and neuromuscular

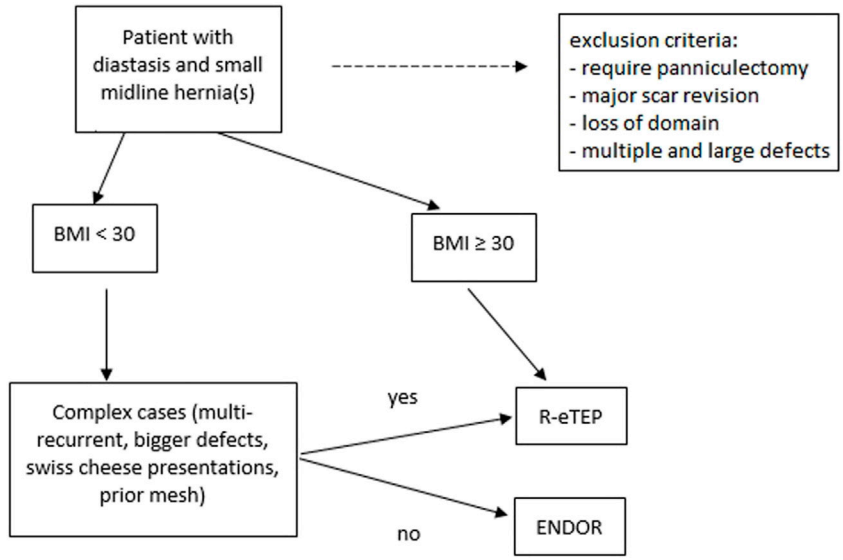

FIGURE 1 | Algorithm to the treatment of ventral hernias associated to Diastasis of the Rectus.

reeducation for patients with minimal symptoms or not interested in undergoing surgical intervention [1, 2, 15–17].

For symptomatic small ventral midline hernias with associated symptomatic or asymptomatic DRAM, open and minimally invasive techniques either *via* laparoscopy or robotic surgery with or without the use of mesh are available [1, 2, 7, 18–21]. In our practice, we utilize mesh reinforcement for all of our patients and propose the following algorithm.

For patients with symptomatic umbilical hernias with DRAM requiring panniculectomy (excess skin flaps from weight loss or prior pregnancies, skin ulceration, previous scars), we perform an open approach with plication of the DRAM and hernia repair with onlay mesh.

If the patient has high cosmetic expectations, we refer our patients to the Plastic and Reconstructive surgery team to perform a conjoint abdominoplasty with the plication of the DRAM and hernia repair with onlay mesh. We have excluded patients undergoing open repair as the aim of this study is to describe our minimally invasive surgery (MIS) algorithmic approach.

For patients who do not require a panniculectomy, we perform an Endoscopic Onlay Repair (ENDOR) if the BMI is <30 mg/kg^2. The rationale for not offering this approach for patients with BMI>30 is based on our published experience with a higher Surgical Site Ocurrences (SSO) rate in these patient populations.[7]ENDOR is the first choice for these patients as it offers easier ergonomics for traditional laparoscopic skills, allows anterior plication of the DRAM (preventing a cosmetically undesirable anterior ridge) and an onlay mesh positioning (maintaining a virgin retromuscular plane in case of a potential recurrence).

For patients with symptomatic small ventral midline hernias with DRAM with BMI ≥30, we perform a Robotic Extended Totally Extraperitoneal repair (R-eTEP) with posterior plication of the DRAM, and hernia repair with sublay retromuscular mesh to decrease the wound morbidity of an ENDOR technique for these patients (**Figure 1**).

Technique

Robotic extended totally extraperitoneal ventral hernia repair

The patient is placed in the supine position The patient´s hips are placed over the operating table's flexion point. The bed is flexed, extending the working space between the subcostal margin and Anterior Superior Iliac Spine (ASIS) to create more space for our port placement. Next, upon preoperative review of cross-sectional CT imaging, the width of the retro rectus space is measured subsequently marked in the patient. A 5 mm Fios port (Applied Medical) is placed in the Left Upper Quadrant (LUQ) just medial to the lateral edge of the rectus muscle. The retro rectus space is identified under vision after traversing the anterior sheath and rectus muscle, then the port is directed inferiorly at a 45-degree angle, and insufflation is initiated. Blunt dissection is performed to allow space for our second port placement 8 cm below the LUQ port 1 cm medial to the semilunar line to avoid any injuries to the neurovascular bundles. A spinal needle is utilized to ensure a safe tract into the retro rectus space, and an 8 mm robotic port is placed under direct vision. Electrocautery with hook or Maryland dissector is used to create space inferiorly for an additional 8 mm robotic port at the Left Lower Quadrant (LLQ), 8 cm inferiorly. At this time, the camera is switched to the inferior port to complete our dissection superiorly, providing good exposure prior to docking the robot and the initial 5 mm optical trocar is exchanged for an 8 mm robotic port. The robot is docked from the right side of the patient. We initiate our dissection lateral to medial towards the linea alba performing a cross over at the epigastric area, taking advantage of the preperitoneal fat tissue of the round ligament of the liver, into the contralateral retro rectus space starting distally from the defect progressing towards the hernia, identifying the hernia sac and reducing its contents into the abdominal cavity. After our

TABLE 1 | Patient demographics.

	eTEP (*n* = 57)	ENDOR (*n* = 24)
	n (%)	n (%)
Sex		
Female	37 (64.9)	19 (79.2)
Male	20 (35.1)	5 (20.8)
Mean age, years (range)	54.8 (34–80)	45.7 (27–64)
Mean BMI, kg/m^2 (±SD)	32 (4.8)	28 (3.6)
ASA		
I	1 (2)	9 (37.5)
II	29 (51)	15 (62.5)
III	26 (45)	0
IV	1 (2)	0
Hypertension	27	5
Diabetes Mellitus	15	3
Hypercholesterolemia	23	3
Smoking	6 (10.5)	1 (4.2)
Former smoker	18 (31.6)	0
COPD	3 (5.3)	0
CAD	3 (5.3)	0
Stroke/CVA	2 (3.5)	0
MI	1 (2)	0
CKD	2 (3.5)	0

eTEP, extended totally extraperitoneal; ENDOR, endoscopic onlay repair; BMI, body mass index (kg/m^2); ASA, American society of anesthesiologists physical status classification; COPD, chronic obstructive pulmonary disease; CAD, coronary artery disease; CVA, cerebrovascular accident; MI, myocardial infarct; CKD, chronic kidney disease.

TABLE 2 | Hernia types.

	eTEP (*n* = 57)	ENDOR (*n* = 24)
	n (%)	n (%)
Isolated Umbilical (M3)	5 (8.8)	11 (45.8)
Isolated Epigastric (M2)	2 (3.5)	2 (8.4)
Multiple defects (M2/M3)	50 (87.7)	11 (45.8)
Recurrent hernia	19 (38.0)	8 (72.7)
Incisional	31 (62.0)	3 (27.3)

eTEP, extended totally extraperitoneal.
ENDOR, endoscopic onlay repair.
M2/M3, European Hernia Classification of Ventral Hernias.

dissection is complete, we measure the defect's length and width, including the DRAM, ensuring 3–5 cm overlap. At this point, any opening on the peritoneum or posterior fascia is closed using running 3–0 barbed slowly absorbable sutures. We, then, plicate the DRAM, including the hernia defect's closure with a running 0 barbed slowly absorbable 180 sutures. We then transition to laparoscopy to introduce the mesh, fixed in two points (suprapubic and subxiphoid) with 0 vicryl® trans fascial sutures to help positioning; once the mesh lays flat in the retro rectus space, we proceed to deflate the abdomen completing the procedure. Drains are not routinely used.

Endoscopic Onlay Repair

The patient is placed supine under general anesthesia, with a slight extension of the hip and the legs abducted. The surgeon is positioned between the patient's legs and the assistant laterally.

A 2 cm transverse incision just above the pubis is performed, followed by subcutaneous dissection exposing the rectus abdominis muscle's anterior aponeurosis. The subcutaneous tissue is separated from the anterior aponeurosis with monopolar cautery both superior and laterally to create sufficient space for the placement of a 12 mm camera port and two 5 mm working ports bilaterally. A purse-string suture is performed in the suprapubic incision to secure the camera port and prevent CO_2 leakage. The subcutaneous tissue is dissected off the rectus muscle's anterior aponeurosis with electrocautery maintaining a CO_2 insufflation at 8–10 mmHg. The umbilicus is disinserted from the aponeurotic muscle plane, and the dissection is extended superiorly to the xiphoid process and 12–15 cm laterally towards the ribs. The hernia sac is dissected, and the contents are reduced to the abdominal cavity. In our experience, if a peritoneal violation occurs, we have not encountered a limited exposure to the operative field. Next, we plicate the DRAM with a running suture to approximate the edges of the rectus muscles with 0 barbed suture 180. The suture line extends from the xiphoid to at least 2–3 cm below the umbilicus. A polypropylene or monofilament polyester mesh is introduced in the craniocaudal direction from the xiphoid to the 3–4 cm below the umbilicus with a lateral overlap of at least 3–5 cm. The mesh may be self-gripping or can be secured with tackers, suture, or glue. The umbilical stalk is fixated back to the musculoaponeurotic plane through one or two simple sutures, and a closed drain suction is introduced *via* a lateral port to prevent seroma formation.

RESULTS

A total of 81 patients were included on the analysis. A R-eTEP was performed in Fifty-seven patients, and twenty-four underwent an ENDOR technique. Patients' demographics are as listed in **Table 1**.

R-eTEP Cases

Thirty-seven (65%) patients were female, the mean age was 54.8 (±10.6), and the mean BMI was 32 (±4.8) (**Table 1**). Hernia characteristics are as listed in **Table 2**. Fifty patients (87.7%) had multiple defects, nineteen (38%) had a recurrent hernia, and thirty-one (62%) presented an incisional hernia. Mean defect width was 4.3 cm (±1.9) and mean mesh area 507.4 cm^2 (±128.2) (**Table 2**).

All patients underwent a robotic approach, and the perioperative outcomes are listed in **Table 2**. The mean operative time was 200 (±62.4) minutes. The hernia defects were closed in all patients, and the mesh was secured with cardinal sutures in most cases (72%). We utilized fibrin sealant in conjunction with cardinal sutures in five cases. Two patients were converted to a hybrid operation. One case presented extensive fibrosis from a prior procedure leading to a challenging exposure and the second case was due to an incarcerated bowel who ultimately needed to undergo a segmental resection. Patients' outcomes are as listed in **Table 3**.

The median LOS was 1 day (0–12), and the median follow-up was 103 days (10–713). Five patients developed post-operative seromas, and one patient developed a post-operative hematoma, which all resolved spontaneously (**Table 4**).

ENDOR Cases

Twenty-four patients underwent an ENDOR approach. Nineteen patients were female (79.2%), mean age was 45.7 years (±11.7), with

TABLE 3 | Perioperative results.

	eTEP (*n* = 57)	ENDOR (*n* = 24)
	n (%)	n (%)
Surgical Approach		
Robotic	57 (100)	3 (12.5)
Laparoscopic	0	21 (87.5)
Mean Surgical time (min), (SD)	200 (±62.4)[a]	146.2 (±51.1)[a]
Median Estimated blood loss (ml)	20 (0–300)[b]	10 (5–40)[b]
Median defect area (cm^2)	30 (2–570)[b]	4 (1–81)[b]
Mean defect width (cm)	4.3 (±1.9)[a]	2.2 (±1.6)[b]
Mean mesh area (cm^2)	507.4 (±128.2)[a]	317.1 (±119.2)[a]
Mesh fixation		
None	1 (2)	1 (4.2)
Tacks	3 (5)	2 (8.4)
Suture	41 (72)	1 (4)
Fibrin glue alone	0	7 (29.2)
Fibrin glue and suture	4 (7)	13 (54.2)
Fibrin glue and tacks	1 (2)	0
Suture and tacks	7 (12)	0
Median Length of Stay (days)	1 (0–12)[b]	0 (0–3)[b]
Conversion to open	2 (3.5)	0
Intraoperative complication		
None	53 (93)	23 (95.8)
Serosal tear	2 (3.6)	0
Bleeding	1 (1.7)	1 (4.2)
Enterotomy	1 (1.7)	0

eTEP, extended totally extraperitoneal.
ENDOR, endoscopic onlay repair.
[a]*Standard Deviation.*
[b]*Range.*

TABLE 4 | Postoperative outcomes.

	eTEP (*n* = 57)	ENDOR (*n* = 24)
	n (%)	n (%)
Post-operative complications		
No	51 (89.5)	19 (79.2)
Seroma	5 (8.8)	4 (16.6)
Hematoma	1 (1.7)	0
SSI	0	1 (4.2)
Hernia Recurrence	0	2 (8.3)
30 days readmission	0	1 (4.2)
Follow-up	54 (94.7)	24 (100)
Median follow-up, days (range)	103 (10–713)[a]	48.5 (10–523)[a]

eTEP, extended totally extraperitoneal.
ENDOR, endoscopic onlay repair.
[a]*Range*

a mean BMI of 28 (±3.6) (**Table 1**). Thirteen patients had isolated umbilical or epigastric hernias (**Table 2**). Three patients (12.5%) were submitted to a robotic approach. Mean defect width was 2.2 cm (±1.6) and mean mesh area was 317.1 (±119.2) (**Table 2**). The mean operative time was 146.2 min (±51.1). Mesh was predominantly fixated with a fibrin sealant and suture. There was no conversion to open surgery or from robotic to laparoscopic surgery. Only one patient had intraoperative bleeding due to a tacker, which was not significant. Most patients underwent same day of surgery, with our longest LOS reported of 3 days (**Table 2**). Four patients developed post-operative seromas, one requiring readmission and drainage due to infection. The majority of patients (87.5%) had a subcutaneous drain placed, which was removed during the first post-operative office visit 2 weeks after the surgery, or when the output was less than 50 cc/day. The Median follow-up was 48.5 days (10–523), and two patients developed a hernia recurrence (**Table 4**). One patient was a heavy smoker that refused to stop smoking and the other patient did not take care of her drain, developing an infected seroma treated with percutaneous drainage and IV antibiotics.

DISCUSSION

The treatment of small ventral hernias with concomitant DRAM remains a subject of debate with no clear guidelines or quality evidence to support an optimal approach when these entities coincide [10, 11]. As the field of hernia surgery continues to evolve with the expansion of MIS approaches, several techniques have been described in the literature for the management of ventral hernias with DRAM [7, 8]. Surgical correction of DRAM follows two main trends, plication versus midline mesh reinforcement and both methods seem to be safe, with high patient satisfaction in support of the correction of this entity [1, 14, 22, 23]. More importantly, failure to correct a DRAM at the time of ventral hernia repair is associated with higher recurrence rates which demands attention and correction when both entities are present.

In our practice, we incorporate plication and mesh reinforcement, and we stratify our patients to an MIS or open repair with an algorithmic approach with the aim of achieving an individualized and optimal cosmetic and functional outcome. In our experience, most of our patients are mainly driven by the functional limitations elicited by their symptomatic hernias, therefore we have noticed an inclination towards MIS interventions where an abdominoplasty with the assistance of the plastic surgery team is not performed, and therefore we have excluded these cohort of patients from our results.

This MIS approach performing a subcutaneous dissection above the anterior rectus sheath has been described by different authors with several modifications [7, 8, 18, 19, 24] to this technique and we refer to it as ENDOR (Endoscopic Onlay Repair) in an attempt to utilize a standardized term. In regard to our technique, we perform an ENDOR for patients with BMI<30 to decrease the associated wound morbidities that we noticed from our initial experience with this approach. The patients selected for ENDOR are healthier patients with smaller defects, however we limit our exclusion criteria to BMI>30 rather than patient specific comorbidities or hernia size defect. The patient's characteristics and hernia defect size remained homogeneous in our expanded series, in patients who underwent and ENDOR approach. Since our initial report in 2020, we have expanded our series to 24 patients with similar outcomes reporting a 16.6% rate of postoperative seromas compared to 18% from our initial experience and no additional recurrences (2%) from our initial series [7].

The evidence supporting minimally invasive approaches for ventral hernia repairs is well established in the literature, and the application of the robotic platform for complex abdominal wall reconstruction has grown over the past years [9]. The general principles in hernia repair of mesh utilization, access to the retro muscular space, primary fascial closure of the hernia defects and a MIS approach are all achieved with the application of robotic surgery [9].

The known benefits of decreased recurrence with mesh placement in the retro muscular space compared to Onlay, inlay or Sublay techniques as well as the lower incidence of surgical site infections supports our choice to perform robotic eTEP for patients with higher BMIs in the setting of small ventral hernias with associated DRAM [9].

While we support the use of the robotic platform for these cases, one of the limitations to this approach is the availability and surgeon's proficiency with the utilization of the robot which may limit the application of this algorithmic pathway. However, it is worth mentioning that retro muscular access *via* a laparoscopic approach is also feasible which may permit the adoption of this pathway in the absence of the robotic Platform [23]. In 2019, Lu et al, performed a comparative review of outcomes for laparoscopic versus Robotic ETEPs with comparable outcomes between the two [25]. However, we believe there is a benefit to the use of the robotic platform particularly for higher BMI patients and larger defects where laparoscopy may be challenging. From a cost benefit standpoint, Warren et al. compared the direct hospital cost between laparoscopic IPOM vs. robotic retro muscular repairs and found no statistically significant difference.[26].

In our study, as expected in our algorithm, patients submitted to R-eTEP were older with more comorbidities and higher BMI. Furthermore, they had more incisional hernias and multiple defects than patients submitted to ENDOR. The patients included on the R-eTEP group included the small ventral midline hernias with DRAM and a broader spectrum of presentations with multiple midline hernias, recurrent and incisional, always associated with DRAM. Additionally, patients with BMI <30 and multiple defects such as inguinal hernias associated to ventral hernias, were also submitted to a R-eTEP procedure, which adds to the advantages of accessing the retromuscular space in these scenarios. That factor explains the higher complexity of demographics and presentations. Interestingly, despite a more complex cohort of patients, in our experience, we did not have recurrences in patients submitted to a R-eTEP so far. While it appears that a R-eTEP confers better post-operative outcomes regarding seroma formation and recurrences when compared to an ENDOR when evaluated individually, we have to consider that a larger sample size in the ENDOR group may likely yield comparable results in regards to seroma formation. In addition, none of the post-operative seromas required interventions; therefore, we still advocate for an ENDOR in patients with lower BMI. Overall, our short-term follow-up limits our ability to evaluate long-term outcomes regarding recurrences for both groups and will be a topic for evaluation in our long-term follow-up studies.

R-eTEP is not the first option for all patients. This technique requires the robotic platform, which is not always available, has a high operative time, and is technically more challenging. It explores the retrorectus space, which would preclude re-approaching this space in the event of a recurrence and disrupts the linea alba due to the transection of the posterior rectus sheath. On the other hand, ENDOR is technically easier and does not use the retrorectus space. The main disadvantage is the seroma formation as reported by several authors [25, 18, 7]. Both techniques avoid intraperitoneal mesh with its possible complications and the need for extensive fixation with tackers or sutures which can lead to acute or chronic pain.

Limitations

Our study has several limitations. First, it is a retrospective, single-center study with a small sample. Data is also limited to short-term outcomes in the current study. Long-term variables, including chronic pain, quality of life measures, and aesthetic outcomes after repair of the diastasis, are essential to consider in future studies. Furthermore, information regarding long-term follow-up and recurrence rates is necessary to determine the effectiveness of repairing a diastasis in reducing recurrence rates in VHR. Finally, a cost analysis evaluation was not available.

CONCLUSION

An algorithmic approach for adequate patient selection was shown to be safe for treating ventral hernias with concomitant DRAM.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Montefiore Medical Center—Albert Einstein School of Medicine. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

Study design: FM, PS, and DL. Data collection and analysis: DL, CM, and JX. Manuscript preparation and editing: CM, DL, JX, PS, and FM.

CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Association Between Inter-Recti Distance and Impaired Abdominal Core Function in Post-Partum Women With Diastasis Recti Abdominis

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Background and Aim: The definition and management of Diastasis Recti Abdominis (DRA) is under debate. This study aimed to understand the correlation between the post-partum inter-recti distance (IRD) and functional impairments associated with core instability, with the hypothesis that IRD could serve as a proxy for core instability symptoms and constitute a tool in decision-making for DRA treatment.

Material and Methods: A cohort of post-partum women with abdominal core instability symptoms combined with DRA were studied. The size of IRD was measured with ultrasonography and cross-sectionally analysed against functional impairments registered with the self-report Disability Rating Index (DRI), which grades the ability to perform 12 different daily activities.

Results: A total of 224 women were included in the study. In univariable analysis, IRD was associated with impairment of the activities running ($p = 0.007$), heavy work ($p = 0.036$) and exercise/sports ($p = 0.047$), but not with dressing, walking, sitting for long periods, standing bent over a sink, carrying a suitcase, making a bed, light manual labour or heavy lifting. No significant correlations were seen in the multivariable analysis when adjustments were made for BMI and parity.

Conclusion: IRD and post-partum functional impairments had no significant correlation in multivariable analysis. The post-partum core instability condition is complex and probably associated with more factors than solely the IRD. The IRD alone does not seem to be a sufficient proxy for decision-making regarding optimal treatment. A more complete instrument to assess the post-partum abdominal core is warranted.

Keywords: diastasis recti abdominis, rectus diastasis, post-partum, inter-recti distance, disability rating index

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INTRODUCTION

Diastasis recti abdominis (DRA) is an anatomical change of the abdominal wall with increased separation of the two rectus abdominis muscles (1). The condition often manifests as a vertical bulging of the anterior abdominal wall during muscle contraction (2). DRA typically represents a post-partum event among women (3). DRA in men is associated with increased intra-abdominal pressure such as visceral obesity (4). Owing to the mechanical stretching and hormonal changes that occur during pregnancy, increased interrecti distance is a normal and common physiological event among childbearing women (1), but may turn into a debilitating DRA condition. The DRA usually regresses after delivery but persists in 32%–46% (5,6,7). Recommended assessment methods for measuring the IRD are ultrasonography, callipers, or CT scan (8).

DRA is often associated with symptoms related to impaired abdominal core function such as trunk muscle weakness (9) and poor body image (10). It may also lead to lumbopelvic pain (1, 11) and urinary incontinence (12). The correlation between the persistent post-partum anatomical changes and the variety of functional symptoms is not fully understood and no generally accepted treatment is yet established (6, 13). Knowledge is insufficient regarding the consequences and management of DRA (7). The impairment is not considered a true hernia and there is consequently no risk for strangulation (14). However, it is associated with an increased risk of developing midline hernias (15,16,17).

The first-line treatment of DRA has traditionally consisted of non-invasive management (18, 19). Some studies show that physiotherapy is beneficial in patients with DRA but in general, the scientific quality is too poor to draw any conclusions (8, 20). If physiotherapy does not result in an adequate recovery, surgery is an alternative. Women who have undergone DRA surgery report an increased functional level and higher quality of life compared to before surgery (17,21,22,23,24,25,26). The purpose of surgical repair of the DRA is to restore the anatomy and thus re-establish abdominal core function. Improved abdominal wall contour is sometimes also lifted as a purpose, even in the absence of functional impairment. Several methods have been described with improved functional results (21, 27).

Although DRA has been a well-known phenomenon, it is only in recent years that surgical treatment with a focus on functional recovery has been considered. The potential functional benefits of surgical treatment and discussions of what previously has been considered as cosmetic surgery have led to significant media attention lately. Many women with DRA experience a lack of understanding from the public health care system regarding their symptoms and may turn to private clinics for surgical management (28).

There is a lack of knowledge regarding risk factors, clinical consequences, and management of DRA (29). Consequently, the accessibility and information to patients varies widely between different county councils and regions. A more standardised and evidence-based management regarding DRA is needed and suggested guidelines have been presented during the last years (8, 28, 30).

Functional impairment such as back pain, abdominal core instability, urinary incontinence and abdominal bulging is common following pregnancy. The ongoing debate is mainly focused on the DRA as a predictor for post-partum functional disabilities (18). Although women with functional impairment associated with DRA, have shown to benefit from surgery, the relationship between IRD and symptoms remains unclear. Some women with great IRD may lack symptoms of DRA. The present study, however, focused only on women with a history of symptoms that could be correlated to DRA.

This study aimed to investigate the association between the inter-recti distance (IRD) and self-reported functional disabilities measured with the Disability Rating Index questionnaire (DRI), with the hypothesis that inter-recti distance could serve as a proxy for abdominal core instability symptoms and constitute a tool in decision-making of DRA treatment.

METHODS

The study was based on a cohort of post-partum women with core instability symptoms combined with DRA. Participants were later considered either for core stability training or surgical repair of the DRA. They were recruited between January 2015 and June 2020. Demographic data, age, BMI, number of births and type of delivery [vaginal/caesarean section] was collected at baseline, as well as the IRD measured with ultrasonography. Some of the women in the present cohort were included in a previous study where they underwent surgery without any specific preoperative training program (17).

Assessment of DRA

All participants were assessed with ultrasonography in a standardised procedure, in a supine position with knees flexed to 90° and relaxed abdominal muscles. The examination was performed with a 40 mm linear transducer. IRDs exceeding 40 mm were assessed with a panoramic view. The IRD was registered in mm at its widest point. An IRD exceeding 30 mm was considered as a potential surgical case (17). The width of 30 mm was chosen as it is widely accepted as a threshold for surgery. The examinations were performed by a senior surgeon with documented training in ultrasound examination, or by a radiologist. Results were recorded and saved in the patients' medical records.

Assessment of Functional Symptoms

Functional symptoms were registered with a self-report questionnaire, the Disability Rating Index (DRI), **Figure 1** (31). The validated DRI covers twelve non-specific activities of daily life: dressing without assistance, outdoor walks, climbing stairs, sitting, standing bent over a sink, carrying a bag, making a bed, running, light work, heavy work, lifting heavy objects and

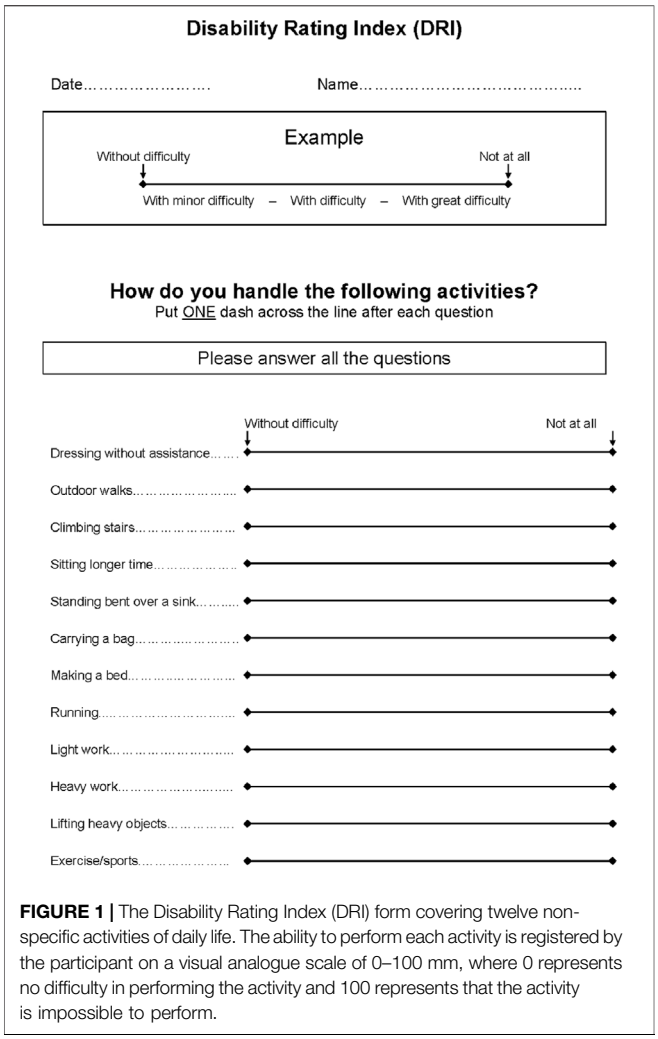

FIGURE 1 | The Disability Rating Index (DRI) form covering twelve non-specific activities of daily life. The ability to perform each activity is registered by the participant on a visual analogue scale of 0–100 mm, where 0 represents no difficulty in performing the activity and 100 represents that the activity is impossible to perform.

exercise/sports. The ability to perform each activity is registered by the participant on a visual analogue scale of 0–100 mm, where 0 represents no difficulty in performing the activity and 100 represents that the activity is impossible to perform.

Ethical Considerations

Written informed consent was obtained from all participants before inclusion. The Regional Ethics Committee, Karolinska Institutet, Stockholm, approved all procedures (Dnr. 2015/1753-31).

Statistical Analysis

Continuous values for characteristics and DRI at the first visit are presented in medians with interquartile range (IQR). Differences of the categorised exposure (</≥3 cm IRD) were tested with the Kruskal-Wallis test. A linear regression model was used, with DRI as a dependent variable, to assess a possible association between DRI and IRD. Multivariable analyses were additionally adjusted for BMI and parity continuously. Two-sided p-values <0.05 were considered statistically significant. To test for non-linearity, DRI was modelled as a quadratic term.

RESULTS

A total of 224 women were included in this study. Of these, 208 women were examined with ultrasonography and completed the questionnaire at their first visit to the outpatient clinic, while sixteen completed the questionnaire retrospectively (two by letter and fourteen *via* telephone interview).

In this cohort, there was no difference in age, BMI, or parity when the IRD was categorised as </≥3 cm. Participants with an IRD ≥3 cm seemed to have more difficulties performing the specific tasks in the DRI compared with those with an IRD <3 cm (**Table 1**). No evidence of non-linearity was found.

In univariable linear regression analysis, an increased DRI was associated with more difficulties in performing some of the heavier activities (e.g., running [p = 0.007], heavy work [p = 0.036] and exercise/sports [p = 0.047], visualized in **Figure 2**. However, the mean increase in DRI-score was small per centimetre increment in IRD (5p for running, 3p for heavy work, respectively 3p for exercise/sports, on a scale from 0 to 100). Combining the five heaviest categories, each one-cm increment in DRI was associated with a 14 p increase in DRI-score (p = 0.038). No association was observed between IRD and DRI when the linear model was adjusted for BMI and parity (p > 0.17, **Table 2**). Interpretation of the results was similar when restricting the analyses to participants with an IRD ≥5 cm and when categorising IRD </≥5 cm (data not shown).

DISCUSSION

Pregnancy often results in persistent anatomical changes of the abdominal wall, such as an increased inter-recti distance that can contribute to core instability, back pain and a poor body image.

DRA has been suggested to explain these functional impairments that affects a substantial proportion of the female post-partum population. The results of this study indicate a slight association between an increased IRD and impaired ability to perform more strenuous daily activities, but this effect fails to

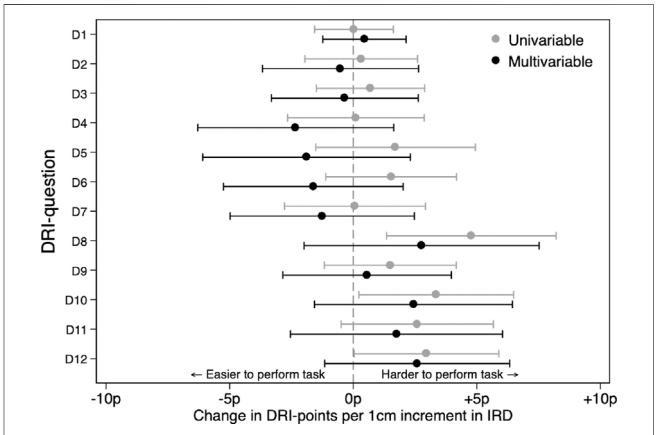

FIGURE 2 | Linear regression analyses with DRI as dependent variable and DRI as independent. Multivariable were also adjusted for BMI and parity.

TABLE 1 | Characteristics, ultrasound values, DRI values of participants.

	Total (n = 224)	Interrecti distance		*p*-value[a]
		<3 cm (n = 8)	≥3 cm (n = 216)	
Characteristics				
Age, years	39 (21–67)	35.5 (34–44)	39 (21–67)	0.35
Body Mass Index, kg/m^2	22.4 (17.0–36.0)	23.2 (19.5–29.6)	22.4 (17–36)	0.56
Parity	2 (1–5)	2 (2–2)	2 (1–5)	0.25
Vaginal	2 (0–5)	1 (0–2)	2 (0–5)	0.10
Sectio	1 (0–4)	1 (0–3)	1 (0–4)	0.94
Inter-recti distance, cm				
Ultrasound	4.5 (2.0–12.0)	2.3 (2–2.8)	4.8 (3–12)	(N/A)
Intraoperative, *n* = 164[b]	5 (3–13)	4.5	5 (3–13)	(N/A)
Abdominal Trunk Function Protocol				
Specific DRI (0-100p)				
Get dressed and undress without help	1 (0–81)	0 (0–7)	1 (0–81)	0.53
Taking walks	5 (0–95)	0 (0–45)	6 (0–95)	0.049
Walk on stairs	4 (0–94)	0 (0–45)	4 (0–94)	0.11
Sitting down for a longer period of time	24 (0–96)	0.5 (0–44)	25 (0–96)	0.011
Stand bent over doing dishes	38 (0–100)	1 (0–51)	40 (0–100)	0.005
Carry a suitcase or bag	24 (0–100)	1.5 (0–64)	27 (0–100)	0.066
Making the bed	11 (0–100)	0 (0–65)	13 (0–100)	0.051
Running	50 (0–100)	0 (0–77)	50 (0–100)	<0.001
Light manual labour	18 (0–100)	0 (0–51)	18 (0–100)	0.007
Heavy manual labour	53 (0–100)	3.5 (0–88)	55 (0–100)	<0.001
Heavy lifts	63 (0–100)	23.5 (0–100)	66 (0–100)	0.013
Exercise/sports	50 (0–100)	3.5 (0–78)	50 (0–100)	0.002
DRI points for the 7 lightest categories (0-700p)	121 (0–574)	15.5 (0–282)	130 (0–574)	0.019
DRI points for the 5 heaviest categories (0-500p)	234 (0–500)	44.5 (0–394)	243 (0–500)	0.003
Overall DRI points (0-1200p)	373 (0–1,063)	62.5 (0–676)	390 (0–1,063)	0.001

Values are medians (range) unless otherwise indicated.

[a]*p-values for differences across categories of IRD were obtained using the Kruskal-Wallis test.*

[b]*N = 1 patient underwent surgery with an interrecti distance <3 cm.*

TABLE 2 | Association between IRD in cm and symptoms at first visit.

	Change in DRI-points for each cm increment in inter recti distance (95% CI)			
	Univariable	*p*	Multivariable[a]	*p*
Specific DRI[a]				
Get dressed and undress without help	0 (–2–2)	0.98	0 (–1–2)	0.59
Taking walks	1 (–1–3)	0.78	–1 (–4–3)	0.75
Walk on stairs	0 (–3–3)	0.53	–1 (–4–3)	0.75
Sitting down for a longer period of time	0 (–3–3)	0.94	–2 (–6–2)	0.25
Stand bent over doing dishes	2 (–2–5)	0.30	–2 (–6–2)	0.37
Carry a suitcase or bag	2 (–1–4)	0.25	–2 (–5–2)	0.38
Making the bed	0 (–3–3)	0.96	–1 (–5–2)	0.50
Running	5 (1–8)	0.007	3 (–2–8)	0.25
Light manual labour	1 (–1–4)	0.27	1 (–3–4)	0.74
Heavy manual labour	3 (0–6)	0.036	2 (–2–6)	0.23
Heavy lifts	3 (-0–6)	0.10	2 (–3–6)	0.42
Exercise/sports	3 (0–6)	0.047	3 (–1–6)	0.17
DRI points for the 7 lightest (Get dressed -> Making the bed)	4 (–10–18)	0.57	–7 (–25–11)	0.42
DRI points for the 5 heaviest (Running->Exercise/sports)	14 (1–28)	0.038	10 (–7–27)	0.25
Overall DRI points	19 (–5–44)	0.13	3 (–30–35)	0.87

[a]*Adjusted for Body Mass Index as a continuous variable, and number of parities.*

reach significance when covariates are considered. This study can therefore not present a significant correlation between DRA alone and self-reported functional impairments, indicating that the persistent post-partum core instability condition is more complex than solely caused by the widened linea alba. The findings of this study suggest that the DRA alone might not explain the panorama of physical symptoms associated with post-partum core instability.

The entire abdominal wall is progressively widened and stretched during pregnancy. A persistent deformation of the abdominal wall

may affect the abdominal trunk function in various ways. A classification based on different myoaponeurotic deformities, including several anatomical changes, has been presented by Nahas (32) who concluded that abdominal wall protrusions are caused by the stretching of the entire abdominal wall and not only the linea alba. This is in line with our results; the pathogenesis of post-partum functional impairments is complex and cannot be explained by the DRA alone.

The different myofascial components of the abdominal trunk co-operate through fascial tension to maintain posture, stabilise the lumbar spine, enable motion and contribute to physiological functions (such as gastrointestinal and respiratory). Traditionally, a reduced IRD has been suggested to be the main focus of DRA rehabilitation (33), while studies focusing on general abdominal core function suggest that the transverse abdominal muscles (TrA) play an important role in maintaining abdominal wall tension (34, 35). Pre-activation of the TrA before a curl-up increases the abdominal wall tension and reduces the IRD-narrowing during the contraction, with less distortion of the linea alba. This may allow better force transfer between the flanks of the abdominal wall. The function of the abdominal muscles increases with TrA activation since it optimises tension of the linea alba despite reduced IRD narrowing (34, 35).

Multiple studies have shown that surgical repair of the DRA improves several functional disabilities (21). A surgical re-approximation of the widened linea alba reduces the abdominal circumference, which results in a stabilisation of the abdominal wall as well as a reduction of several functional symptoms (21). Although there is no significant correlation between IRD and DRI in this study there are several reports of functional improvements following surgical reduction of the inter-recti distance. Pieces of the puzzle are still lacking and there are obviously more aspects to this complex situation that need further investigation.

Post-partum core instability, causing back pain and abdominal muscle weakness, is well known by physiotherapists and personal trainers. There are numerous different training concepts recommended for reducing functional disabilities in the post-partum population (36). Multiple studies have reported both positive and negative results after non-specific training (20), while specific core stabilising training has been reported to provide an improved abdominal core function (18) and could be considered before surgical management of the DRA (8). The effect of core training is primarily to stabilise the abdominal canister and not reduce the inter-recti distance (28), although some studies have reported a decreased IRD following training (37).

The IRD is considered an important finding for deciding treatment but the definition of an abnormal IRD varies (8, 28, 30). Four of the 12 parameters tested with the DRI-scale (running, heavy work, lifting heavy objects and exercise/sports), showed a moderate correlation between the diastasis width and disability in performing the task in the univariable analysis, but there was no significant correlation between the width of the inter-recti distance and the degree of reported symptoms in the multivariable analysis. Our study suggests that even a modest IRD may have an impact on the associated functional impairments affecting daily life but the IRD alone does not seem to be sufficient to determine whether surgical reconstruction of a deformed abdominal wall is needed or not. However, although the current study only included eight participants with an IRD <3 cm, our data suggests that this group is less likely to be as functionally impaired as those with an IRD ≥3 cm.

Women with DRA perceiving functional impairment constitute a neglected patient group that deserve more attention. There is no consensus among health professionals on how to best approach the condition (38). Patient-reported outcome measures are valuable tools to evaluate clinical symptoms such as body image and core instability. When surgical repair is considered, a shared decision-making between the patient and the surgeon is crucial. A comparable situation is the management of osteoarthritis patients waiting for an arthroplasty. Osteoarthritis can be confirmed with radiology, but radiological findings generally do not correlate well with symptoms (39). Instead, the patient's preferences play a significant role when deciding if a total hip or knee arthroplasty is necessary. Some patients wish to continue an active lifestyle whereas others request surgery to enable performance of simple daily living activities (40). This approach may apply also to diastasis recti abdominis.

LIMITATIONS

This is a cross-section investigation without a control group. There were no data on concomitant midline hernias that might have had a confounding effect on reported functional disabilities. In twelve cases (5%), women who accepted inclusion fulfilled the DRI retrospectively. Therefore, we cannot exclude a response bias impact.

The participants' activity levels have not been included in the calculations, possibly affecting the interpretation of the DRI reports. For someone who does not perform strenuous daily activities—the inability to perform these might not have been considered a problem when completing the DRI. Participants' waistlines have not been recorded either. A certain IRD might constitute a larger problem for someone with a small waistline compared to someone with a greater waistline.

The cut-off level of 30 mm was chosen as it is widely accepted as a threshold for surgery. There is, however, no natural anatomical reason for choosing this level. When deciding on surgery, not only the width of the DRA should be taken into account.

As we did not have an *a priori* hypothesis regarding the relationship between the inter-recti distance and abdominal function, we did not do regular sample size estimation. It is possible that the present study is underpowered and that there may be a weak relationship that we were unable to detect. The uneven distribution, with only eight women with inter-recti distance less than 3 cm, also decreased the statistical power.

The outcome measures in the present study were purely subjective. Objective measures, e.g., trunk function assessed with Biodex®, may have provided more precise outcomes with higher inter-rater reliability.

As the aim of the study was to assess whether a predefined inter-recti distance could be set as a threshold for deciding on surgery, we analyse it as a dichotomous variable. However, linear analysis may have shown a significant correlation.

CONCLUSION

Many post-partum women with persistent DRA suffer from functional disabilities. This study did not show any significant correlation between self-reported functional impairments and the inter-recti distance in isolation, even though there was a tendency towards an association between DRA and the ability to perform strenuous activities. The post-partum core instability condition is complex and consists of more components than solely the inter-recti distance. More research is needed to understand the interaction between anatomy and function, develop better assessment instruments and optimise the treatment. The inter-recti distance as well as other anatomical measures should also be evaluated in studies with greater statistical power than the present one.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The Regional Ethics Committee, Karolinska Institutet, Stockholm, approved all procedures (Dnr. 2015/1753-31). The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

LB wrote the manuscript with substantial support from all co-authors. Data was collected by AO. Statistical analyses were performed by OS. Interpretations of results were conducted mainly by OS, AO, GS, and LB.

CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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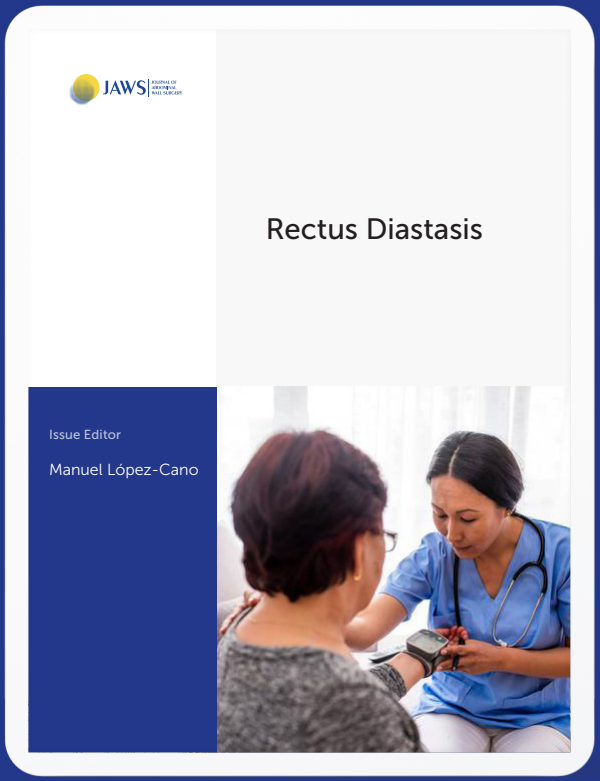

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