Faculty of Medicine
University of Helsinki

RECTUS DIASTASIS:

EPIDEMIOLOGY AND OPERATIVE TREATMENT

Reetta Tuominen

DOCTORAL DISSERTATION

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Supervised by

Jaana Vironen, MD, PhD
Adjunct Professor
Abdominal Center, Helsinki University Hospital
University of Helsinki, Finland

Tiina Jahkola, MD, PhD
Adjunct Professor
Department of Plastic Surgery, Helsinki University Hospital
University of Helsinki, Finland

Reviewed by

Minna Kelloniemi MD, PhD
Adjunct Professor
Department of Plastic Surgery, Tampere University Hospital
University of Tampere, Finland

Timo Heikkinen MD, PhD
Adjunct Professor
Terveystalo
University of Oulu, Finland

Opponent

Agneta Montgomery, MD, PhD
Associate Professor
Department of Clinical Sciences, Malmö
Lund University
Malmö, Sweden

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CONTENTS

LIST OF ORIGINAL PUBLICATIONS

This thesis is based on the following publications:

I. Tuominen R, Vironen J, Jahkola T. “Case series of a novel open plication supported by mesh (PSUM) - technique for symptomatic abdominal rectus diastasis repair with or without concomitant midline hernia: Early results and a review of the literature”, International Journal of Abdominal Wall and Hernia Surgery (2019) 2,4, 2 142-148

II. Tuominen R, Jahkola T, Saisto T, Arokoski J, Vironen J. ” The prevalence and consequences of abdominal rectus muscle diastasis among Finnish women: an epidemiological cohort study”, Hernia (2021) 26(2):599-608.

III. Tuominen R, Jahkola T, Mikkonen J, Luomajoki H, Arokoski J, Vironen J. ” Low back pain and motor control dysfunction after pregnancy- the possible role of abdominal rectus muscle diastasis”, (submitted 2022).

IV. Tuominen R, Peltoniemi H, Jahkola T, Vironen J. “An abdominoplasty modification for post-pregnancy abdomen with rectus diastasis and midline hernia: the technique and results”, Plastic and reconstructive surgery (accepted 2022)

The publications are referred to in the text by their roman numerals.

ABBREVIATIONS

ARD	Abdominal rectus diastasis
ASLR	Active straight leg raise
BMI	Body mass index
cm	centimeter
CT	Computed tomography
EO	External oblique muscle
HELP	Hydrodissection and epidural anesthesia for lateral plication
HRQoL	Health-related quality of life
IO	Internal oblique muscle
IPOM	Intraperitoneal onlay mesh
IRD	Inter-rectus diameter
LBP	Low back pain
mm	millimeter
n	number
PGP	Pregnancy-related pelvic girdle pain
PSUM	Plication supported by mesh
PLBP	Pregnancy-related low back pain
RCT	Randomized controlled trial
RD	Rectus diastasis
TLF	Thoracolumbar fascia
US	Ultrasound
WARP	Wide abdominal rectus plication
yr	years

ABSTRACT

Background

During pregnancy, the abdominal wall expands and linea alba stretches. Although the abdominal wall usually reverts after delivery, for some the recovery is only partial and rectus diastasis may persist. This thesis consists of studies addressing different aspects of post-pregnancy rectus diastasis (RD). The project was initiated to study the changes of the linea alba width after pregnancy and to determine what is normal inter rectus distance after pregnancy and what can be considered abnormal. In addition, we wanted to determine if there is a threshold level for linea alba width that is associated with increased RD-related symptoms. The aim was to find evidence for treatment indications in public health care.

RD concerns the following two surgical specialties: general and hernia surgery and plastic and reconstructive surgery. The treatment algorithms in these specialties have not been the same. One aim of this thesis was to evaluate surgical outcomes together with health-related quality of life (HRQoL) following operative treatment. Two techniques are reported in this thesis.

Midline hernia is relatively common in connection with diastasis. Umbilical hernia repair in general is one of the most common procedures performed. Treatment guidelines consider this patient group as one entity and tailored solutions based on etiology or patient characteristics are not considered. This thesis describes a subgroup of midline hernia patients that may benefit from a different approach than that suggested in widely accepted international hernia guidelines.

Material, Methods, and Results

In Study I, a minimally invasive, novel PSUM-mesh technique targeted to treat severe diastasis with and without a midline hernia is presented. Thirty-seven patients between June 2014 to May 2018 were operated. The mean inter-rectus distance (IRD) was 5.2 cm (range 4.0–9.0 cm). This is wider than in previous patient series in the abdominoplasty literature. Sixteen patients had an umbilical hernia and 3 an epigastric hernia. Patient-reported retrospective results were good; 80% had a reduction in back pain and 96% had a reduction in core instability. This study is a baseline work for an ongoing randomized controlled trial (RCT) where patients are randomized to PSUM and classical plication techniques (ClinicalTrials.gov NCT03509376). This RCT is presumed to be completed in 2024.

In Study II, the width of the linea alba of 939 women was measured during early pregnancy screening ultrasound. Over 400 women answered the HRQoL and symptom questionnaires. In this large cohort, the average IRD in

nulliparous women was 1.81±0.72 cm, which is considered normal. Already after one pregnancy, IRD was 2.36±0.83 cm, which is classified as mild diastasis. After two or more pregnancies, the rectus bellies are even farther from each other (mean IRD 2.55 ± 1.09 cm). HRQoL or back pain did not differ in groups under or over 3 cm IRD. Severe diastasis (IRD >5 cm) was rare. Only 1.5% had severe diastasis in study cohort. These results do not support 3 cm as one of the indications for surgery.

In Study III, the same questionnaires as in Study II were repeated in the same cohort a year after index pregnancy. A minority of women reported increased back pain or core instability. In Study III, we recruited individuals from this symptomatic subgroup and controls who reported no change in their bodily experience after index pregnancy. IRD was measured with ultrasound in 14 cases and 41 controls. The study groups did not differ at baseline; mean IRDs were 2.41±1.01 cm in the symptomatic case group and 2.29±1.03 cm in the control group. A year later, symptomatic cases had significantly wider mean IRD (3.26±0.90 cm) than controls (2.47±0.79 cm). There was a significant difference in the sit-up test; in 30 seconds, symptomatic individuals performed 4.7±4.2 sit-ups and controls performed 8.2±3.9.

As the abdominal wall expands during pregnancy, linea alba is not the only structure that elongates. Firmness of the abdominal wall also depends on lateral fascia structures, as these may be permanently saggy. In Study IV, we report in detail HELP abdominoplasty for treatment of RD with and without a midline hernia. This study reported the total plicated distance in a quantitative manner addressing lateral laxity. After HELP-abdominoplasty, rectus bellies were immediately side by side after 2 years of follow up. There were no hernia recurrences in the series even though mesh technique was not used. Total complication rate was <10%. Patients reported excellent outcomes.

Conclusions

A 2–3 cm wide IRD is common especially after several pregnancies, but this does not seem to cause RD-related symptoms. Severe, persistent RD is rare. Surgery is an effective treatment for women with wide post-pregnancy diastasis or prominent abdominal protrusion together with back pain or core instability. Post-operative HRQoL significantly improves. The complication rate with HELP abdominoplasty is low. If a normal-weight female patient develops a midline hernia after pregnancy, a thorough evaluation of the entire abdominal wall should be performed. In case of concomitant RD, the primary problem of loose, excess, low-quality linea alba and fascia is the primary target for surgery and hernia is a secondary issue.

TIIVISTELMÄ

Johdanto

Raskauden aikana kasvava kohtu ja lapsi venyttävät naisen vatsanpeitteitä ja samalla vatsalihakset erkaantuvat toisistaan. Synnytyksen jälkeen vatsanpeitteiden muutoksen pääosin palautuvat, mutta joillakin tämä prosessi jää vaillinaiseksi. Tämän väitöskirjan tavoitteena oli selvittää, miten vatsanpeitteet keskimäärin toipuvat raskaudesta ja mikä on pitkällä aikavälillä tavallinen suorien vatsalihasten väli synnytyksen jälkeen. Tutkimuskokonaisuus pyrkii lisäksi tuomaan lisätietoa erkauman eri vaikeusasteiden aiheuttamista oireista väestötasolla ja tarjoamaan siten lisätietoa leikkaushoidon indikaatioihin julkisessa terveydenhuollossa.

Kirurgisesti erkaumaa hoidetaan sekä vatsaelinkirurgian että plastiikkakirurgian erikoisaloilla ja käytettävät leikkaustekniikat ja osin indikaatiot ovat vaihdelleet. Väitöskirjan yhtenä tavoitteena oli paneutua operatiivisen hoidon menetelmiin ja tuloksiin.

Erkauman venyttämässä ja haurastuttamassa keskilinjan lihaskalvossa tavataan varsin usein napa- ja sydänalatyriä. Keskiviivan tyrä vatsanpeitteissä on yleinen ja napatyrän korjaus on yksi tavallisimmista leikkauksista. Hoitosuositukset käsittelevät keskiviivan tyristä kärsiviä potilaita yhtenä joukkona, eikä räätälöityjä ratkaisuja tyrän etiologian tai potilasryhmän mukaan ole juurikaan esitetty. Väitöskirja kuvaa erkauman aiheuttaman tyrän, jonka hoito mahdollisesti poikkeaa yleisestä hoitosuosituksesta.

Aineisto, menetelmät ja tulokset

Osatyössä I kuvataan säästävän, erityisesti leveän erkauman ja tyrän hoitoon soveltuvan uuden PSUM- verkkoleikkaustekniikan pilottisarjan tulokset. Sarjassa oli 37 potilasta. Leikkaukset toteutettiin 6/2014–5/2018 välisenä aikana Jorvin sairaalassa. Keskimääräinen erkauman leveys oli leveäksi luokiteltava 5,2 cm (vaihteluväli 4,0–9,0 cm), mikä on enemmän kuin julkaistussa erkaumaa ja abdominoplastiaa käsittelevässä kirjallisuudessa. Erkauman lisäksi 16 potilaalla oli napatyrä ja 3 potilaalla sydänalatyrä. Retrospektiiviset tulokset olivat hyvät: 80 %:lla selkäkipu helpotti ja 96 % koki vartalon hallinnan parantuneen leikkauksen jälkeen. Tutkimus on parhaillaan käynnissä olevan satunnaistetun, vertailevan tutkimuksen esityö. Satunnaistetussa tutkimuksessa leikataan sokkoutetusti PSUM- tekniikalla sekä klassisella plikaatiolla erkaumapotilaita, millä saadaan laadukkaampaa tutkimustietoa operatiivisesta hoidosta (ClinicalTrials.gov NCT03509376). Kyseinen työ valmistuu alustavasti vuonna 2024.

Osatyössä II mitattiin suorien vatsalihasten väli varhaisen raskauden seurantaultraäänitutkimuksen yhteydessä 939 naiselta. Yli 400 vastasi kyselytutkimukseen. Osatyössä synnyttämättömillä naisilla keskimääräinen suorien vatsalihasten väli oli 1,81±0,72 cm, mikä on nykyisten määritelmien

mukaan normaaliksi katsottava. Jo yhden raskauden jälkeen keskimääräinen suorien vatsalihasten väli oli kuitenkin erkauman diagnostiset kriteerit täyttävä, 2,36 cm± 0,83 cm. Kahden tai useamman synnytyksen jälkeen suorat vatsalihakset sijaitsivat yhä kauempana toisistaan ja keskimääräinen suorien vatsalihasten väli oli 2,55 ± 1,09 cm. Tutkimuksen mukaan, kyseisellä lievällä linea alban leventymisellä ei kuitenkaan ole vaikutusta elämänlaatuun tai selkäoireisiin. Leveä, yli 5 cm erkauma puolestaan on hyvin harvinainen. Synnyttäneiden naisten joukossa vain 1.5 %:lla oli leveäksi luokiteltava suorien vatsalihasten väli. Tuloksilla on mahdollista osaltaan tarkentaa leikkaushoidon indikaatioita.

Osatyössä III selvitettiin, onko indeksiraskauden jälkeen enemmän selkäkivun ja vartalonhallinnan suhteen oireilevilla eroa suorien vatsalihasten välisessä mitassa verrattuna heihin, joilla kokemus vartalosta ei muutu raskauden jälkeen. Lähtötilanteessa oireisten ja oireettomien ryhmillä ei ollut eroa suorien vatsalihasten mitassa ja keskimääräinen suorien vatsalihasten väli oli oireisilla 2,41±1,01 cm ja kontrolleilla 2,29±1,03 cm. Vuosi synnytyksen jälkeen ryhmät erosivat suorien vatsalihasten välin suhteen: oireisilla väli oli 3,26±0,90 cm ja oireettomilla 2,47±0,79 cm. 30 sekunnin istumaannousutestissä oireisilla suoritus oli 4,7±4,2 ja oireettomilla 8,2±3,9.

Kun vatsanpeitteet raskaudessa työntyvät eteenpäin, linea alba ei ole ainoa venyvä rakenne. Toipumisvaiheessa lihaskalvo voi jäädä veltoksi paitsi keskiviivasta myös lateraalisesti. Osatyössä IV kuvataan HELP-abdominoplastia erkauman ja samanaikaisen napa- ja sydänalatyrän hoidossa. Artikkelissa raportoidaan kvantitatiivisella tavalla lihaskalvorakenteen kokonaisvaltainen korjaus. HELP-abdominoplastian jälkeen suorat vatsalihakset olivat tiukasti vierekkäin kahden vuoden seurannassa verifioituna UÄ-mittauksella. Tyrät eivät olleet uusineet, vaikka hoitosuosituksessa ehdotettua verkkoa ei käytetty. Haittavaikutukset olivat vähäisiä ja leikkauksen hyödyt subjektiivisesti merkittävät.

Yhteenveto

Yhteenvetona voidaan todeta, että raskaus muuttaa tulevan äidin vatsanpeitteitä. 2–3 senttimetrin levyinen suorien vatsalihasten väli on tavallinen erityisesti useamman raskauden jälkeen. Tämä ei yleensä lisää oireisuutta. Leveä, pysyvä erkauma synnytyksen jälkeen on harvinainen. Silloin kun leveään erkaumaan yhdistyvät selkäkipu, vartalon hallinnan vaikeudet tai huomattava vatsanseinämän työntyminen eteenpäin, kirurginen hoito tarjoaa hyvän avun. Leikkauksen jälkeen elämänlaatu paranee merkittävästi. Leikkausriskit ovat maltilliset. Jos potilaalla on raskauden jälkeinen keskiviivan tyrä, on olennaista arvioida vatsanpeitteet kokonaisuudessaan. Silloin kun tyrään yhdistyy erkauma, hoito tulee suunnitella erkauma huomioon ottaen.

1 INTRODUCTION

Divarication of abdominal rectus muscle bellies and the widening of linea alba is a consequence of increased abdominal cavity volume (Hernández-Granados et al., 2021). The most common causes of rectus diastasis (RD) are pregnancy, obesity, and aging (P. G. F. da Mota et al., 2015; Reinpold, Kockerling, et al., 2019; Yuan et al., 2021). This thesis is focused on post-pregnancy RD. Pregnancy progressively stretches the entire abdominal wall, including linea alba. Every pregnant woman has transient RD in the last trimester (Sperstad et al., 2016). Abdominal wall and linea alba revert approximately a year after delivery (Gitta et al., 2017). For some women, the recovery is only partial and the linea alba remains permanently wide. This persistent post-pregnancy RD causes symptoms for some women (Emanuelsson et al., 2016; Gunnarsson et al., 2015; Toranto, 1990). Core instability and impaired body image are associated with symptomatic RD (Hernández-Granados et al., 2021). Back pain and disability, incontinence, and bulging contour of abdominal wall with protruding umbilicus mimicking umbilical hernia are also associated with RD (Emanuelsson, Gunnarsson, et al., 2014; Taylor et al., 2018). Studies discussing the effects of diastasis and the predisposing factors have mostly defined RD with dichotomous grading with a low cutoff limit for RD. There are only few studies where severe diastasis (not pooled with mild diastasis) and symptoms have been analyzed.

Plain RD has traditionally been managed conservatively. Although several different training programs have been described, there is no consensus on recommended therapy (Akram & Matzen, 2014). The control of core muscles and the ability to prevent bulging of the abdomen outwards is essential in rehabilitation. For some individuals, core control is impossible due to a saggy fascia-muscle layer that is supposed to be firm.

The operative management of rectus diastasis has been controversial. Recently, the indications for operative treatment have been published both nationally and internationally with weak quality of evidence (Carlstedt et al., 2020; Hernández-Granados et al., 2021). RD is operated in two surgical specialties (general and hernia surgery and plastic and reconstructive surgery) and the indications and treatments strategies differ. A variety of surgical techniques have been described, such as linea alba plication (suture) with or without mesh augmentation, via an open or laparoendoscopic approach (Reinpold, Kockerling, et al., 2019). There is no consensus on the recommended technique (Mommers et al., 2017). In the Pitanguy technique described in 1967, the fascia is plicated in the midline using non-absorbable suture. Since then, plication of the anterior rectus sheath has been the most used technique for repair of RD when abdominoplasty is performed. There is an abundancy of plication techniques. Although the available evidence

suggests that after plication the recurrence rate for diastasis is low, there is little imaging validation of the results (ElHawary et al., 2020).

The fascia heals poorly. For example, primary closure of ventral abdominal wall hernias is accompanied with a high recurrence rate. Furthermore, the overall incidence of incisional hernia after laparotomy is approximately 10% (Nho et al., 2012). In hernia repair, mesh augmentation is evidence-based to ensure a strong and reliable abdominal wall closure (Bittner et al., 2019). When midline hernia and RD occur concurrently, a mesh technique is suggested (Hernández-Granados et al., 2021). It is worth noting that guidelines do not acknowledge the heterogeneity of hernia patients. It is possible that obese patients with "too little" fascia may differ from a normal weight post-partum female with "too much" stretched, loose fascia.

Modern medicine considers health-related quality of life (HRQoL) measurements as an equal endpoint compared with objective parameters (Staquet et al., 1996). Patient-reported outcomes provide patient perspective on results and reveal different aspects of the patient's own experience of their well-being, including physical, mental, emotional, and social aspects.

This thesis examined the changes of linea alba width after pregnancy, the consequences of abdominal RD, and surgical outcomes together with HRQoL following operative treatment. In the first study, a novel, minimally invasive PSUM-mesh technique with a retrospective patient series is reported. In the second study, the focus was on the epidemiology of inter-rectus measurements (IRD) and determining the threshold IRD for increase in symptoms. In the third study, linea alba width was compared between those with more back pain and core stability problems after pregnancy and those reporting no change in symptoms. In the fourth study, the results of HELP abdominoplasty and assessment of lateral laxity of the abdominal wall are described. Details of the operative technique are presented. Patient-reported outcomes with HRQoL instrument RAND-36 are evaluated together with ultrasound imaging and functional measurements.

2 REVIEW OF THE LITERATURE

2.1 ANATOMY OF THE ABDOMINAL WALL

The anterolateral abdominal wall consists of the following four main layers: skin, superficial fascia (Scarpa's fascia), the firm layer of muscles and associated fascia, and parietal peritoneum. The subcutis consists mainly of a varying amount of adipose tissue. Scarpa's fascia has clinical importance; it is thick in the lower abdomen forming a structure that holds suturing. Superficial vessels and nerves run above the Scarpa's fascia (Moore & Dalley, 1992; Thorne & Chung, 2014).

2.1.1 LINEA ALBA

The linea alba is the firm layer structure in the immediate midline. The name means white line as it has a white appearance. The linea alba separates the two rectus abdominis (RA) bellies from each other and extends from the xiphoid process of the sternum to the pubic symphysis. Rectus muscles are enveloped with rectus sheath (Figure 1). The linea alba and the rectus sheaths are extensions of the fusion of aponeuroses of the lateral abdominal wall muscles, namely the external abdominal oblique (EO), internal abdominal oblique (IO), and transversus abdominis (TA). The linea alba consists of a three-dimensional, structured meshwork of collagen fibers (Axer et al., 2001). The linea arcuata is a horizontal line that demarcates the lower limit of the posterior layer of the rectus sheath. Above the linea arcuata, the internal oblique muscle aponeurosis splits to envelop the rectus abdominis muscle anteriorly and posteriorly (Moore & Dalley, 1992). The anterior layer is derived from the external oblique aponeurosis and the anterior lamina of the internal oblique aponeurosis. The posterior layer is made up of the posterior lamina of the internal oblique aponeurosis and the transversus abdominis aponeurosis. Below the linea arcuata, the aponeuroses of the EO, IO, and TA merge and pass superficial to the RA muscle. Therefore, inferior to the arcuate line, RA rests directly on the transversalis fascia (Moore & Dalley, 1992). The arcuate line varies between individuals but occurs approximately half of the distance from the umbilicus to the pubic crest.

The linea alba balances contractile forces generated by the muscles attached to it and stabilizes the anterior abdominal wall. It can be considered as a tendon of force transfer from right to left and from the lower extremities to the torso and vice versa.

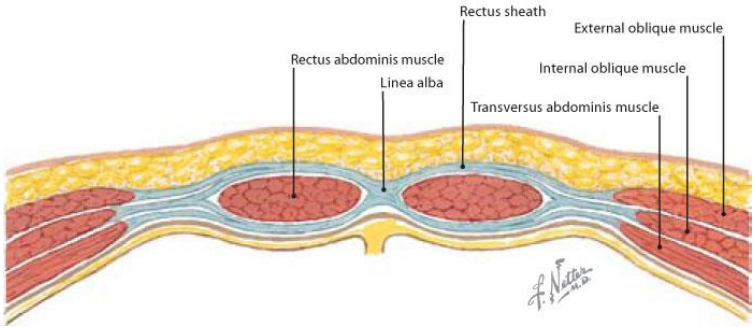


Figure 1 Anatomy of the abdominal wall superior to the arcuate line. *Netter illustration used with permission of Elsevier, Inc. All rights reserved*

2.1.2 MUSCLES OF THE ABDOMINAL WALL

The muscles of the anterolateral abdominal wall can be divided into the following two main groups: three lateral muscles situated on either side of the abdomen and two vertical muscles, situated near the midline of the body (Seeras et al., 2022) (Figure 2). External oblique, internal oblique, and transversus abdominis muscles are located laterally in the abdominal wall. Their fibers cross each other, which reduces the risk of abdominal contents herniating through the wall. The external oblique is the largest and most superficial muscle in the abdominal wall. Its fibers run inferomedial. The internal oblique lies deep to the external oblique. It is smaller and thinner in structure, with its fibers running superomedial-perpendicular to the fibers of the external oblique. The transversus abdominis is the deepest of the flat muscles, with transversely running fibers. The sensory nerves run in an avascular plane between TA and IO. Deep to TA is a well-formed layer of fascia, known as the transversalis fascia. TA, transversalis fascia, and thoracolumbar fascia merges with the anterior margin of the pelvic floor (Roch et al., 2021).

Table 1 Lateral muscles of the abdominal wall

Muscle	Origo	Insertion	Innervation	Function
External oblique	Ribs V-XII	Iliac crest and pubic tubercle	Thoracoabdominal nerves (T7-T11) and subcostal nerve (T12	Contralateral rotation of the torso
Internal oblique	Inguinal ligament, iliac crest, and lumbodorsal fascia	Ribs X-XII	Thoracoabdominal nerves (T7-T11), subcostal nerve (T12), and branches of the lumbar plexus.	Bilateral contraction compresses the abdomen, while unilateral contraction ipsilaterally rotates the torso
Transversus abdominis	Inguinal ligament, costal cartilages VII-XII, iliac crest and, thoracolumbar fascia	Conjoint tendon, xiphoid process, linea alba, and pubic crest	Thoracoabdominal nerves (T7-T11), subcostal nerve (T12), and branches of the lumbar plexus	Compression of abdominal contents, stabilizing the core. Role in spinal stability

There are two vertical muscles located in the midline of the abdominal wall, the rectus abdominis (RA) and pyramidalis (Moore & Dalley, 1992). The RA is a long, paired muscle, found on either side of the midline in the abdominal wall. In spoken language, RA is referred as “the abs”. The lateral borders of the muscles create a line known as the linea semilunaris. Horizontally, the RA is intersected by fibrous strips, known as tendinous intersections. RA originates from the crest of the pubis, inserting into the xiphoid process of the sternum and the costal cartilage of ribs V-VII. RA compresses the abdominal viscera, stabilizes the pelvis during walking, and depresses the ribs. It is innervated by thoracoabdominal nerves (T7-T11).

Pyramidalis is a small triangular muscle found superficially to the rectus abdominis. It is located inferiorly, with its base on the pubis bone, and the apex of the triangle attached to the linea alba. It is a minor muscle and tenses the linea alba and contributes as an assistance muscle in various abdominal wall functions.

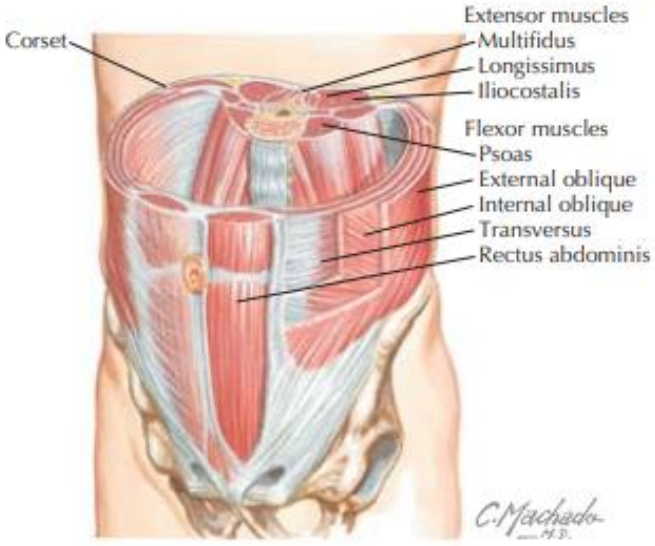


Figure 2 Anatomy of the abdominal wall, coronal plane. *Netter illustration used with permission of Elsevier, Inc. All rights reserved*

2.1.3 THORACOLUMBAR FASCIA AND THE BACK

TA, IO, EO aponeurosis form a continuity with the three layers of the thoracolumbar fascia (TLF): posterior, middle, and anterior layer. The thoracolumbar fascia is a part of a myofascial girdle that surrounds the lower portion of the torso and plays a role in posture, load transfer, and respiration (Willard et al., 2012). The TLF is a deep investing membrane that covers the deep muscles of the back. The posterior layer of TLF is attached to the spinous processes of the lumbar and sacral vertebrae and to the supraspinal ligament. The middle layer is attached to the tips of the transverse processes' lumbar vertebrae and to the intertransverse ligaments. The anterior layer covers the Quadratus Lumborum and attaches to the bases of the transverse processes of lumbar vertebrae and the last rib.

The three layers of TLF unite at the lateral margin of the paraspinal muscles to form the tendon of origin of the TA.

2.1.4 BLOOD SUPPLY OF THE ABDOMINAL WALL

The anterolateral abdominal has rich vascular supply (Figure 3).

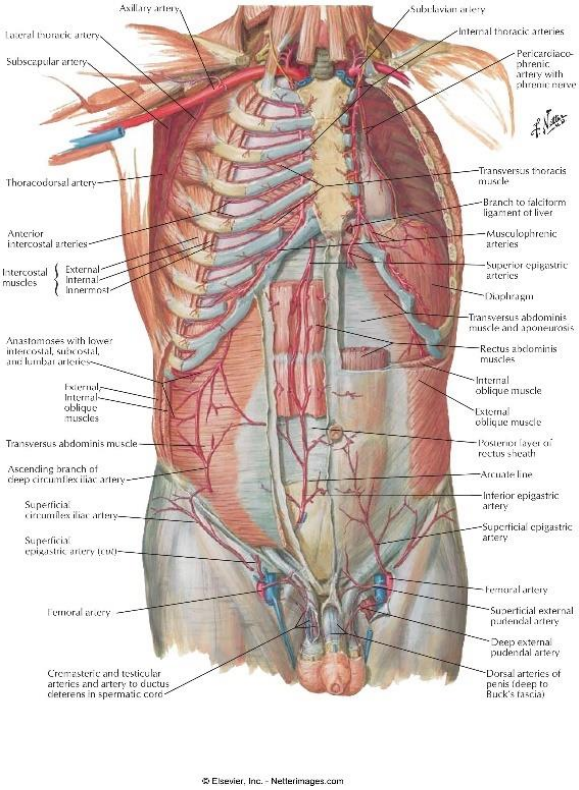


Figure 3 Arteries of the abdominal wall. *Netter illustration used with permission of Elsevier, Inc. All rights reserved*

The abdominal wall can be divided into three vascular territories (Mayr et al., 2004) (Figure 4).

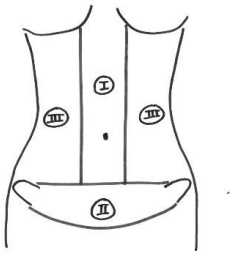


Figure 4 Vascular territories of the abdominal wall.

Zone 1 ranges from the xiphoid to the pubis and between the lateral borders of the rectus muscles. This zone is supplied primarily from an arcade formed between the superior and inferior epigastric arteries.

Zone 2 is the area defined superiorly by a line from the anterosuperior iliac spine and inferiorly by the groin and the pubic creases. Zone 2 receives its blood supply from the superficial epigastric, superficial circumflex iliac, and external pudendal arteries (superficial system) and from the inferior epigastric vessels (deep system). Lateral abdomen and flanks comprise Zone 3. This area is supplied by segmental lumbar, subcostal, and intercostal branches.

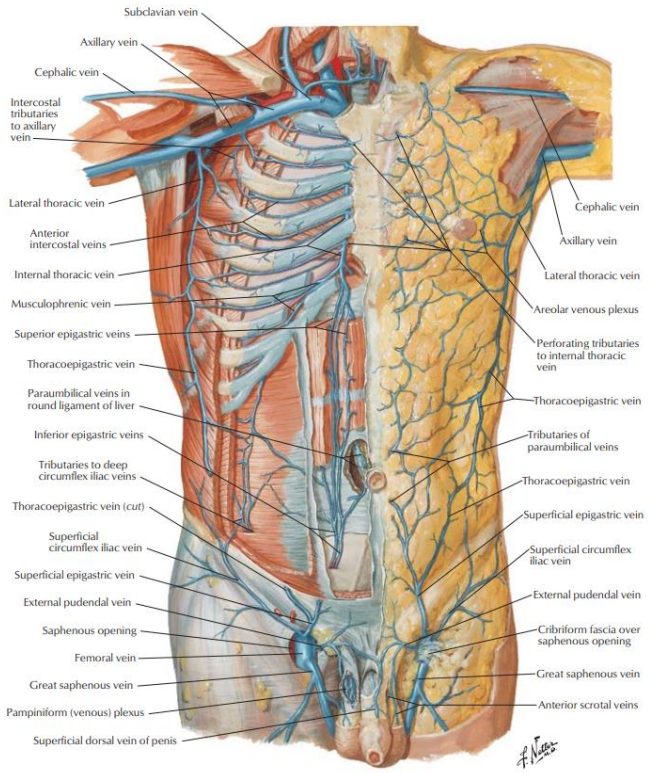


Figure 5 Veins and collateral circulation of the abdominal wall. *Netter illustration used with permission of Elsevier, Inc. All rights reserved*

Abdominoplasty requires undermining of a large skin-subcutis flap and division of the main perforating vessels. After raising the abdominal flap, Zone 1 is perfused with only superior epigastric arteries and the Zone 2 axial blood supply is sacrificed. A flap with a random-pattern blood supply is generated

consisting of blood supply mainly from lateral vessels (Mayr et al., 2004). The blood supply relies largely on the collateral circulation (Figure 5).

2.2 ABDOMINAL WALL FUNCTION

The abdominal cavity encloses a finite volume of contents within its boundaries, which are rigid and nonyielding, except for the anterior abdominal wall, the diaphragm, and partly the rib cage. The abdominal wall keeps the abdominal viscera in the abdominal cavity and assists the viscera in maintaining their anatomical position against gravity. The abdominal wall also protects the abdominal viscera from injury, assists in forceful expiration by pushing the abdominal viscera upwards, and increases intra-abdominal pressure when needed, such as during coughing, vomiting, or defecation (Grevious et al., 2006; Moore & Dalley, 1992; Seeras et al., 2022).

2.3 RECTUS DIASTASIS

Abnormal separation of the two rectus abdominis muscles caused by a thinning and widening of the linea alba is diagnosed as RD (Reinpold, Kockerling, et al., 2019). Pregnancy and obesity (Beer et al., 2009), previous abdominal surgery (Brauman, 2008), and aging (Kaufmann et al., 2021) are the most common causes. It has also been suggested that there is a congenital form of RD caused by lateral insertion of rectus muscle origo (F. X. Nahas, 2001). The normative values of linea alba width have been determined from a nulliparous population (Beer et al., 2009).

2.3.1 CLASSIFICATION

There are some classifications schema of RD, such as the Beer, Ranney, Endohernia Society, and Nahas classifications.

2.3.1.1 Beer

The Beer classification is dichotomous grading of normal and diagnostic IRD. Beer et al. examined 150 nulliparous women between 20 and 45 years of age and with a body mass index (BMI) <30 kg/m^2. The authors concluded that IRD up to 2.2 cm is normal measured 3 cm above umbilicus (Beer et al., 2009).

2.3.1.2 Ranney

Ranney et al. studied 1738 abdominal hysterectomy patients perioperatively and stated that a separation of 2.0–3.0 cm between the rectus muscles is

considered mild diastasis, 3.0–5.0 cm moderate diastasis, and >5.0 cm severe (Ranney, 1990). Normal IRD is classified as IRD <2.0 cm. In the Ranney study, 31.8% patients had mild diastasis, 6.2% had moderate, 0.7% had severe, and 61.9% had a normal IRD.

2.3.1.3 Endohernia Society Classification

The German Hernia Society and the International Endohernia Society presented a proposal of RD classification based on the diastasis level (sub xiphoidal, epigastric, umbilical, infraumbilical, and suprapubic). The width is classified according to Ranney (Reinpold, Kockerling, et al., 2019). The classification was established particularly to enable a precise description of patients being operated for RD. The proposed classification also considers other features in the abdominal wall, such as concomitant hernias, quality of the skin, parameters of previous pregnancies, and pain.

2.3.1.4 Nahas

Nahas classifies RD as types A, B, C, and D that correspond to different myoaponeurotic deformities. Patients with type A exhibit rectus diastasis secondary to pregnancy and constitute the most common form of RD. Patients with type B present laxity of the lateral and inferior areas of the abdominal wall after operative re-approximation of medial rectus sheaths. Patients with type C are those whose rectus muscles are laterally inserted on the costal margins as an anatomical variation. Patients with type D are defined by “poor waistline definition”.

2.4 POST-PREGNANCY RECTUS DIASTASIS

2.4.1 LINEA ALBA DURING PREGNANCY

The abdominal wall expands during pregnancy. Linea alba elongation is due to mechanical and hormonal reasons. (Dehghan et al., 2014). The incidence of RD peaks at the last trimester of pregnancy (Boissonnault & Blaschak, 1988; Liaw et al., 2011; Turan et al., 2011). The prevalence of RD is 100% at gestational week 35 (P. G. F. da Mota et al., 2015).

2.4.2 PERSISTANT POST-PREGNANCY RECTUS DIASTASIS

Linea alba reverts after pregnancy more rapidly in the first 3 months but it continues to revert even after 6 months (Sperstad et al., 2016). The RD incidence is dependent on the definition used. In a study by Mota et al, the prevalence of RD was 39% at 6 months postpartum measured with an

ultrasound at 2 cm below the umbilicus and RD defined as 16 mm (P. G. F. da Mota et al., 2015).

In a study by Sperstad et al, the prevalence of RD was 33.1% at gestational week 21, 60.0% 6 weeks post-partum, 45.5% 6 months post-partum, and 32.6% 12 months post-partum. Here, RD was defined as two or more fingerbreadths separation between the rectus bellies (Sperstad et al., 2016). Based on their study of 84 participants and 90th percentile values, Mota et al concluded that up to 28 mm 2 cm above umbilicus is normal (P. Mota et al., 2018). The width is mostly recommended to be measured 3 cm above the umbilicus (Figure 6).

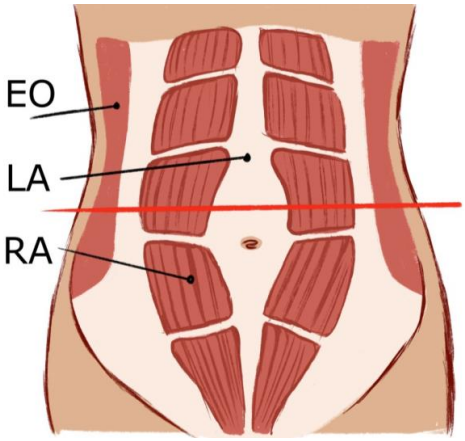


Figure 6 Red line indicates the suggested site of IRD measurement. *EO External Oblique, RA Rectus Abdominis, LA Linea Alba.*

2.4.3 LATERAL LAXITY

During pregnancy, the entire abdominal wall expands, not only the area in between the rectus bellies. The fascia layer also stretches lateral to linea alba. If the lateral wall fascia fails to recover post-partum, lateral laxity is present. It has been proposed that the loose anterior abdominal wall, and not RD alone, is a risk factor for core instability and back pain (Brauman, 2008). Nahas classifies lateral laxity as B-type RD (F. X. Nahas, 2001). Usually, post-pregnancy protrusion of the abdominal wall is a sign of RD, but there is a subgroup of RD patients whose actual RD is mild but there is substantial bulging and RD-related symptoms due to the looseness in the lateral abdominal wall. Figure 7 presents a patient example of a 36-year-old woman who was primarily operated 26 months earlier. She underwent a re-operation because of undesirable scars, protruding abdomen, and ongoing back pain. During the re-operation, the remaining IRD was 3 cm and total plicated fascia distance was 6 cm.

Figure 7 Patient example of the lateral laxity during re-operation. RD had been previously corrected but there was still protrusion of the abdomen and low back pain. At re-operation the residual diastasis was 3 cm, and the total plicated fascia was 6 cm. The loose, excess fascia layer between the fingers of the surgeon is to be plicated.

2.4.4 SYMPTOMS

Various symptoms are associated with RD. In a recent guideline, core instability and poorer bodily self-esteem are mentioned as probable consequences of RD (Hernández-Granados et al., 2021).

In a systematic review, there was weak evidence that RD may be associated with pelvic organ prolapse. RD severity may be associated with impaired HRQoL, impaired abdominal muscle strength, and severity of low back pain (Benjamin et al., 2019). Data are not consistent. In the Mota et al study, women with RD at 6 months postpartum were not more likely to report lumbo-pelvic pain than women without RD (P. G. F. da Mota et al., 2015) .

Figure 8 presents a perioperative example of a flaccid abdominal wall where force transfer is suboptimal. The lateral wall is under tension only when activating the core (Figure 8 b). When the individual fails to control the deep core, anterior support is lost (Figure 8 and c). It is difficult to address this anatomic state with any conservative rehabilitation program. With mild RD and a firm fascia layer, it is understandable that core muscle training can reduce symptoms and surgery can be avoided. The same situation with extrinsic view of observed in Figure 10; the patient must consciously or unconsciously control the stomach for stabilizing the core. If not, the loose

fascia-muscle layer fails to resist intra-abdominal pressure and the abdomen drops forward.

Based on anatomical change illustrated in Figure 8, the bulging of the abdominal wall creates an appearance of the affected individual looking pregnant. In addition to cosmetic effects, RD compromises the function of the abdominal wall, predisposing to muscle imbalance and chronic back pain (Mestak et al., 2012). Functional loss affects daily activity and ranges from being unable to sit up to an inability to enjoy exercise and activities that were enjoyable before RD (Mughal & Ross, 2021).

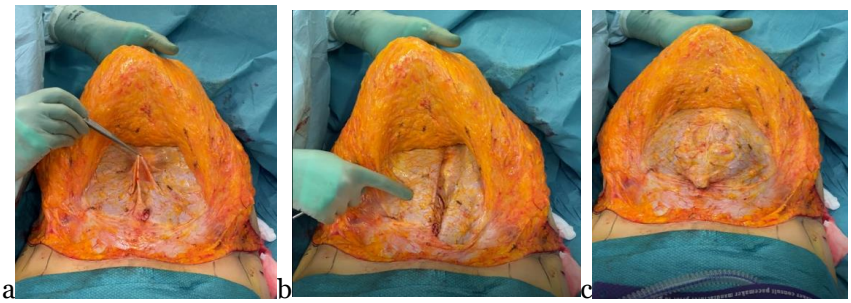


Figure 8 Perioperative example of non-functional fascia layer. a) Loose fascia layer does not support the muscles. b) The patient is under epidural anesthesia on the operating table and asked to lift her head upwards. The lateral abdominal wall tightens. c) The patient is asked to take a deep breath and an extensive protrusion becomes apparent *(Photos courtesy by Hilkka Peltoniemi)*.

Incontinence is one of the symptoms associated with RD. Data are inconsistent. In a study by Braga, RD was not a risk factor for stress urinary incontinence (Braga et al., 2020). Similarly, Fei et al did not find any relationship between RD and urinary incontinence, even when RD was severe (Fei et al., 2021). On the other hand, there is some evidence that operative correction of severe diastasis may improve urinary incontinence (Olsson et al., 2019a; Taylor et al., 2018).

In most cases, studies addressing the correlation of symptoms and RD are performed with dichotomous grading, with low RD as the diagnostic cutoff value. Mild and severe diastasis are pooled together and compared with patients with normal IRD. Less is known on the effects of severe RD (P. G. F. da Mota et al., 2015; Rett et al., 2008; Sperstad et al., 2016; Turan et al., 2011).

2.4.5 PREDISPOSING FACTORS

There are no differences between pre-pregnancy BMI, weight gain, baby's birth weight, or abdominal circumference for women with or without RD at 6 months postpartum (Candido G, 2005; Gitta et al., 2017; Sperstad et al., 2016). There is a significant relation between parity and RD (Turan et al., 2011).

2.4.6 DIAGNOSTICS

The appearance of RD varies (Figure 9).

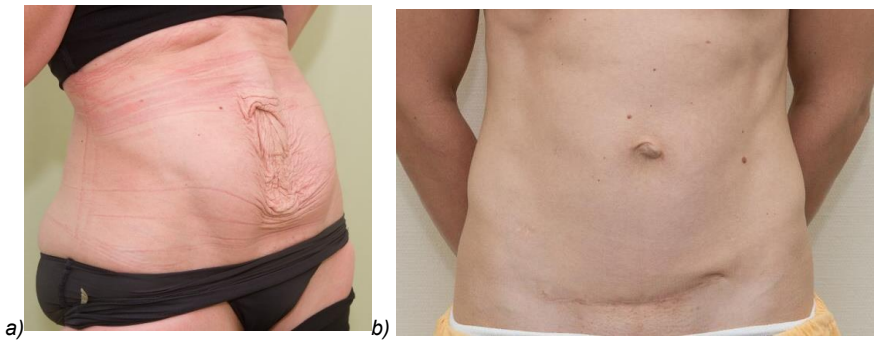
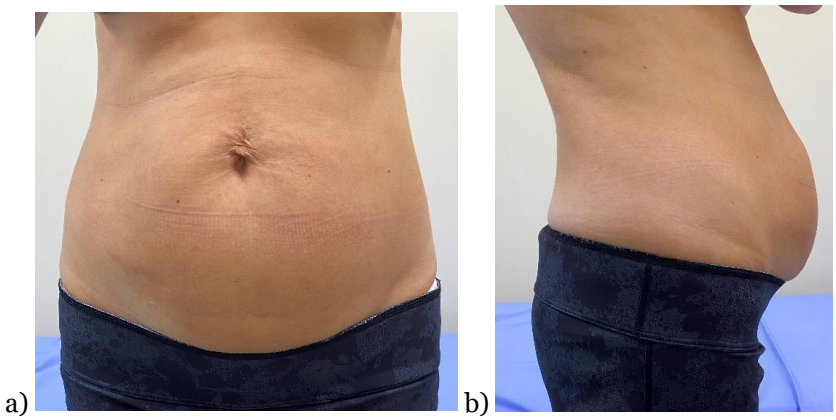


Figure 9 Patient examples of different pre-operative appearances of RD. Sometimes RD is immediately apparent (a) and sometimes RD is less prominent (b).

According to recently published guidelines, clinical examination is the cornerstone for diastasis diagnostics (Hernández-Granados et al., 2021). When diagnostic modalities were compared, the “finger width” method or more precise caliper is recommended. Ultrasound (US) imaging may be beneficial for instance if the rectus bellies are difficult to palpate. In a systematic review, van der Water et al concluded that US and calipers are adequate methods to assess RD (van de Water & Benjamin, 2016), with acceptable test-retest and inter-rater reliability. The finger-width method had lower agreement between raters than calipers or US (van de Water & Benjamin, 2016). US measurement can provide usable information in clinical practice in patient selection.

In clinical examination, it is typical that severe RD or substantial lateral laxity causes the abdomen to protrude significantly in an upright position. When the person lays down, the abdomen flattens (Figure 10).



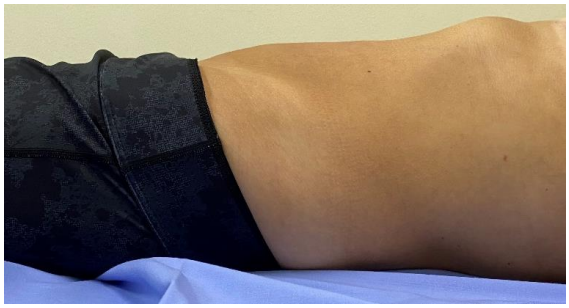
c) 

Figure 10 Patient example of RD and protruding contour of the abdomen. a) Frontal view with 3-cm RD and 7-cm total laxity; b) Side view with typical lordosis in the lumbar spine and with protruding contour of the abdomen in relaxed state; c) Side view supine. Note the flattened contour of the abdomen when compared with b).

Measurement is performed with the patient in a relaxed state, as contraction of abdominal muscles narrows the width of linea alba (Chiarello et al., 2016). If the medial borders of the rectus bellies are difficult to find, they are usually discovered when the patient lies supine and is asked to lift their head upwards from the table. The medial borders of rectus abdominis are more prominent when the muscles contract. When the head is slowly returned to the table, the clinician's fingers slide laterally to note the relaxed IRD (Figure 11).

a)  b) 

Figure 11 Clinical examination of RD. a) During contraction when the patient lifts her head upwards. b) At relaxed state, when head is slowly returned to the table.

Imaging by US examination or CT may be considered to exclude hernia (Henriksen et al., 2020). It is worth noting that a midline hernia is rarely an indication for imaging, as it is recommended that umbilical and epigastric hernias are diagnosed by clinical examination alone. Due to radiation exposure, CT is not a first-line imaging modality (Emanuelsson, Dahlstrand, et al., 2014).

2.4.7 CONSERVATIVE TREATMENT

Physiotherapy and strengthening of abdominal core muscles may have a positive effect on RD symptoms (Chiarello et al., 2005), although the evidence is weak (Chiarello et al., 2005; Lo & Candido, 1999; Thabet & Alshehri, 2019). Physiotherapy programs tend not to reduce IRD in a relaxed state (Mommers et al., 2017). The recommended method of conservative rehabilitation in under debate. Nevertheless, core training is always considered the primary intervention for abdominal wall protrusion and RD (Carlstedt et al., 2020; Hernández-Granados et al., 2021). While the Swedish guidelines recommend a core training program for at least 6 months, the actual training content is not specified (Carlstedt et al., 2020). In the Finnish recommendations for RD management (not published), 6 months of physiotherapy with a written statement from the physiotherapist is suggested.

Increasing core muscle control and power are also important in the case of upcoming surgery. Post-operatively, muscle control protects the suture line. As no specific program is superior to others and the training should be frequent, the patients can choose the most suitable program. The abdomen should not bulge while exercising and the core should be kept in control.

2.4.8 OPERATIVE TREATMENT

The role of surgery in RD treatment is emerging (Akram & Matzen, 2014; ElHawary et al., 2020). The overall evidence for the benefits of surgery is weak and there is no consensus on the treatment of RD (Akram & Matzen, 2014; Carlstedt et al., 2020; Hernández-Granados et al., 2021). The dogma has been that diastasis repair is performed for cosmetic reasons (ElHawary et al., 2020). Consequently, the procedure has not been covered by the public healthcare system or health insurance (Carlstedt et al., 2020; ElHawary et al., 2020). There is growing evidence that RD may also be associated with substantial functional impairment and back pain, core instability, and negative impact on the woman's quality of life (ElHawary et al., 2020; Emanuelsson et al., 2016; Toranto, 1990).

2.4.8.1 Indications

Swedish national guidelines recommend that the largest width of the diastasis should be at least 5 cm before surgical treatment is considered. In case of pronounced abdominal bulging or concomitant ventral hernia, surgery may be considered in patients with a smaller diastasis (Carlstedt et al., 2020). In Finland, a working group of Finnish plastic surgeons suggested in 2021 that the indication for surgery should be an IRD >3 cm. Relevant symptoms were also required for referral to the surgery outpatient clinic together with documented physiotherapy.

2.4.8.2 Contraindications

One to two years should have elapsed since the last childbirth and future pregnancy should not be planned (Carlstedt et al., 2020). With obesity, RD and protrusion of the abdominal wall is natural to allow for the increase in intra-abdominal volume. At Helsinki University Hospital Jorvi, the BMI limit has been 28 kg/m^2. An important clinical judgment is to assess the distribution of adipose tissue; extra in the flanks or hips (pearl-shape body) is less problematic than visceral fat (apple-shape body), suggesting that BMI alone is an insufficient parameter for clinical practice. Smoking is a contraindication for all elective plastic surgery in Finland.

2.4.8.3 Concomitant midline hernia

RD and midline hernia are closely related. RD predisposes to midline hernia and moreover is a significant risk factor for hernia recurrence (Kohler et al., 2015). The quality of the linea alba in the RD patient is often poor. The tissue is overstretched and thin and prone to true hernias. A cohort study of Olsson et al. showed perioperative incidence of concomitant epigastric or umbilical hernia (or both) in 75% of diastasis patients (Olsson et al., 2019b). A retrospective multicenter 10-year study concluded that 56% of men and 36% of women with RD have one or more hernias (Yuan et al., 2021).

On the other hand, RD has only had a minor role in the hernia literature. For example, Oma et al studied 224 female patients in 2016 who became pregnant subsequently after mesh or suture repair of umbilical and epigastric hernia. Median follow-up was 3.8 years (range 0.1–8.1). The cumulative recurrence rate was 16.3% after mesh repair and 10.9% after suture repair (Oma et al., 2016). RD was not considered as a parameter that may have influenced the results.

If herniorrhaphy is first performed with mesh techniques without addressing RD, the RD restoration is sometimes difficult as a secondary procedure, as mesh generates a perpendicular force to resist RD plication. Figure 12 presents a case of recurrent hernia after previous IPOM mesh and RD.

Figure 12 Perioperative view of a patient's third midline hernia operation. The patient originally had an umbilical hernia that was first sutured. Later there was a hernia recurrence treated with IPOM mesh. An epigastric hernia subsequently emerged on the upper border of the mesh. In the operation shown here, the epigastric hernia together with RD were repaired with HELP.

2.4.8.4 Endoscopic techniques and mesh

There are several options for mesh placement in hernia repair (Figure 13). Rives-Stoppa retro-rectus sublay mesh has been the golden standard for incisional and for midline hernias (Hartog et al., 2022; Stoppa, 1989). RD and concomitant hernia have also been operated with an open sublay mesh (Matei & Runkel, 2014). Several new innovations for anatomical restoration of RD with mesh have been described, such as the endoscopic-assisted or endoscopic mini open sublay repair (MILOS) (Reinpold, Schröder, et al., 2019), (EMILOS) (Schwarz et al., 2017), endoscopic-assisted linea alba reconstruction (ELAR) (Kockerling et al., 2017), laparoscopic linea alba stapler repair, enhanced total extraperitoneal ventral hernia repair (eTEP), laparoscopic intracorporeal rectus aponeuroplasty (LIRA) (Gómez-Menchero et al., 2018), preaponeurotic endoscopic repair (REPA)(Juárez Muas, 2019), and totally endoscopic sublay (Luque et al., 2015). The characteristics of these techniques are presented in Table 2.

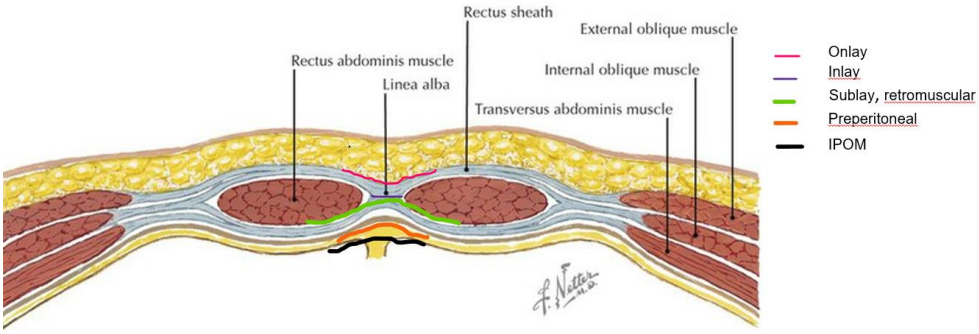


Figure 13 Abdominal wall layers and alternatives of mesh positioning. *Netter illustration used with permission of Elsevier, Inc. All rights reserved*

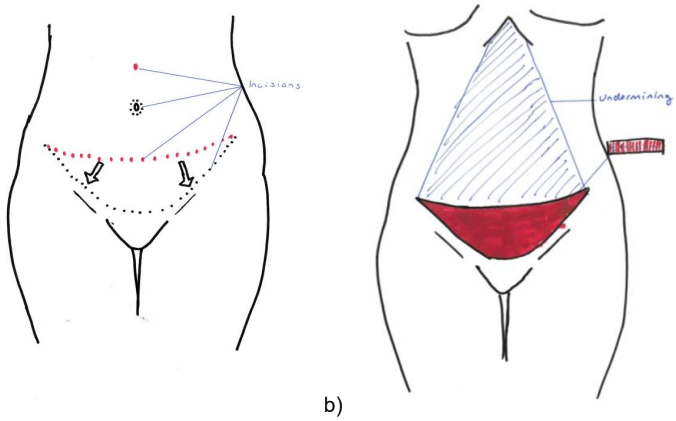
Table 2 Endoscopic techniques for diastasis and hernia repair

Acronym	Technique	Author, Journal (Year)	Inclusion criteria	Plication	Mesh
	Totally endoscopic surgery on RD	Bellido, Hernia, 2014	Hernia >2 cm	Barbed absorbable suture	IPOM (Ventral Patch)
MILOS	Endoscopically assisted minimally or less open subley repair	Reinpold, Ann Surg, 2018	Incisional hernia	No plication	Retromuscular/ preperitoneal, large
EMILOS	Endoscopic mini open subley repair	Schwarz, Langenbecks Arch Surg, 2017	Umbilical, epigastric, or incisional hernia with RD	No plication	Retromuscular 20 x 30 cm
ELAR	Endoscopic assisted linea alba reconstruction	Köckerling, Front Surg, 2016	Umbilical or epigastric hernia with midline protrusion	Rectus sheath anterior layer transposition sutured with non-absorbable suture	Onlay mesh to cover transposed fascia
	Endolaparoscopic linea alba stapler repair	Carrara, Ann Med Surg, 2019,	Midline defect with 4–8 cm RD	Linear stapler	Retromuscular
eTEP	Enhanced total extraperitoneal ventral hernia repair	Belyansky, Surg Endosc, 2018	Ventral or incisional hernia	Barbed suture	Retromuscular

LIRA	Laparoscopic intracorporeal rectus aponeuroplasty	Gómez-Menchero, Surg Endosc (2018)	4–10 cm midline hernia with 3–8 cm RD	Rectus sheath posterior layer transposition sutured with absorbable, monofilament, or barbed non-absorbable suture	IPOM
REPA	Preaponeurotic endoscopic repair	Juárez Muas, Surg Endosc (2019)	Midline defect with RD	Barbed suture	Onlay

2.4.8.5 History of abdominoplasty

Kelly performed the first panniculus excision through a transverse incision as a debulking surgery removing umbilicus (Kelly, 1910). At that time, the safety of anesthesia and post-operative infection risk differed substantially from current surgical conditions. Any surgical intervention possessed major, even lethal risk. As anesthesia and surgery evolved, abdominoplasty techniques improved along with aesthetic considerations. Thorek introduced a technique to preserve the umbilicus (Thorek, 1939). Pitanguy popularized abdominoplasty in 1967 as a technique for augmenting ventral hernia repairs and subsequently for aesthetic improvement of the abdomen. Pitanguy was amongst the surgeons who placed the incisions in the lower abdomen in a "W" manner. Bikini-line incision placement was further promoted by Reganult and Grazer (Grazer, 1973; Regnault, 1972). The principles of abdominoplasty are presented in Figure 14.



a) b)

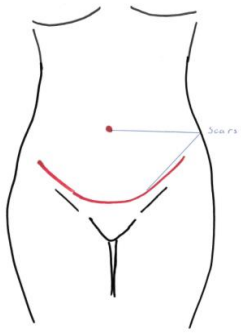


Figure 14 Abdominoplasty a) skin incision, b) skin and subcutis that is to be excised (shown in red) and undermined area (shown in blue), c) final scars.

In 1983, the evolution of abdominal contouring took a leap as liposuction was introduced by Illouz (Illouz, 1972). Liposuction was initially utilized with mini-abdominoplasty to improve contour.

Later, further refinements of abdominoplasty were published, including lateral tension abdominoplasty (Lockwood, 1995), selective undermining, and discontinuous undermining with liposuction (Saldanha et al., 2010).

The design of the umbilicus has interested the plastic surgery community, and there are numerous approaches and modifications (Joseph et al., 2016). The native umbilicus can be incised with a round, oval, or vertical ellipse pattern or a "U" or "inverted U" shape. The most common incision shapes made in the abdominal flap for umbilical reinsertion are a round incision or an inverted "V" or "U". It is common to defatten the subcutaneous adipose tissue around the incision to create a periumbilical concavity. In a review article by Joseph, 40% of the techniques describe suturing the dermis of the umbilical skin to rectus fascia. Furthermore, 30% of the presented techniques consider that stalk plication is advisable.

2.4.8.6 Diastasis repair during abdominoplasty

Pitanguy described the fascia plication in the midline using non-absorbable suture (Pitanguy, 1967). After Pitanguy, various plication techniques have been described, using absorbable (F. X. Nahas et al., 2001, 2011) and non-absorbable sutures (Mughal & Ross, 2021; Oneal et al., 2011; Restrepo & Ahmed, 2002a), interrupted sutures (Mughal & Ross, 2021; Oneal et al., 2011), continuous sutures (Restrepo & Ahmed, 2002a), barbed sutures, and various combinations thereof depending on the amount of suture layers and whether the anterior, posterior, or both rectus sheaths were plicated (Akram & Matzen, 2014). Mesh techniques have also been used in open approaches (Batchvarova et al., 2008; Emanuelsson, Gunnarsson, et al., 2014).

There are clinical practices where the umbilicus is removed and replaced with a neo-umbilicus to minimize the risk of hernia or diastasis recurrence, as no opening for the umbilical stalk remains during fascia plication. In TULUA abdominoplasty, a neo-umbilicus is created. However, in TULUA the fascia plication is performed in a transverse fashion and classical diastasis repair is not performed (Villegas-Alzate et al., 2021). In Jorvi Hospital, the neo-umbilicus approach has not been used unless the umbilicus is severely scarred or is otherwise impossible to be saved.

2.4.8.7 Mini-abdominoplasty in diastasis repair

Mini-abdominoplasty is defined by dissection at the infraumbilical level without supraumbilical undermining (Greminger, 1987; Wilkinson & Swartz, 1986). The definition implicates that diastasis repair cannot be performed above the umbilicus. A modification where only the fascia below the umbilicus is plicated is presented in a textbook of plastic surgery (Thorne & Chung, 2014). Restrepo et al published an abdominoplasty modification characterized by mini-abdominoplasty and liposuction of the abdomen and flanks with a horizontal half-moon on the infraumbilical fascia plication with high lateral tension (Restrepo & Ahmed, 2002b).

Mini-abdominoplasty type incision with floating umbilicus is an option for patients who have moderate excess skin in the infraumbilical area and no or mild excess skin in the supraumbilical area. Diastasis repair from the xiphoideum to symphysis can be performed with the benefit of scarless umbilicus but with the cost of lowering the umbilicus (Wan et al., 2019a).

2.4.8.8 Lateral laxity in diastasis repair

Braumann analyzed 92 consecutive abdominoplasty patients and concluded that abdominal protrusion should replace diastasis as the prime indicator of abdominal wall laxity, as abdominal wall protrusions are caused by the stretching of the entire abdominal wall and not only the linea alba. Abdominal wall protrusions may occur without diastasis. In contrast, some individuals have firm abdomens with RD(Brauman, 2008).

Some other studies also addressed lateral laxity of the abdominal wall. Psillakis discussed flaccidity of the cutaneous and musculoaponeurotic tissues and addressed the deformity by suturing “major oblique muscle” to the rectus fasciae (Psillakis & Guerrero-Santos, 1979). Toranto et al introduced wide abdominal rectus plication (WARP) in 1989. No BMI limit was described in the original article. The plication was standard and aggressive; sutures-of-eight plication was extended to the lateral borders of RA or on EO muscle fascia. After plication, there was a 90° rotation of RA around its long axis (Toranto, 1990). In 24 out of 25 patients, back pain was reduced and the technique was concluded to be an alternative for back-pain patients who have

undergone spinal surgery or physiotherapy without pain relief. Hunstad et al present their WARP technique with additional liposuction (Hunstad & Jones, 2011). IRD or total plicated distance was not reported in these studies.

Nahas managed Group-B patients with lateral laxity with L-shape additional plication on both sides of the hypogastric transversalis muscle aponeurosis after re-approximation of the medial rectus sheaths (F. X. Nahas, 2001).

Ramirez et al introduced a technique plicating RA anatomically without overcorrection. To enhance the waistline in some patients, a plication row lateral to the semilunaris line was added on both sides (A. E. Ramirez et al., 2021).

2.4.8.9 Results of rectus plication

In review articles on RD repair, there were no differences in post-operative complications or recurrence between plication-based methods and hernia repair methods (Akram & Matzen, 2014; Hickey et al., 2011; Mommers et al., 2017). However, most of the evidence is of low quality, as long-term results are still lacking (ElHawary et al., 2020). It is worth noting that the information on pre-operative IRD and RD severity is not reported in most of the available studies (Table 3).

There are only a few objective measurements of IRD after diastasis repair. In the Mestak study, the mean post-operative IRD halfway between the xiphoid and umbilicus was 10.4 mm (range, 0–39 mm) (Mestak et al., 2012). Pre- or perioperative IRD was not reported. On the other hand, pre-operative RD was mild or even normal in some studies (F. X. Nahas et al., 2011). In a prospective study by Swedenhammar et al on the long-term results of RD repair, recurrence was classified as IRD >3.0 cm, although the exact IRDs were not reported (Swedenhammar et al., 2021). In the original paper, the inclusion criterion was IRD wider than 3 cm. In the Swedenhammar study, the post-operative bulging of the abdomen and relatively low satisfaction on aesthetic results surprised the authors. Lateral laxity was not discussed as a possible explanation.

Table 3 Summary of studies (> 12 patients and available in English) that were included in review articles and one RCT on RD repair and the width of the RD pre- and post-operatively

Author	Journal	Year	RCT	N	Hernia	RD pre-op, cm (range)	RD post-op, cm, (range)	Follow up, mo (range)
Kanjoor	IJPS	2012	Akram 2013	146	49	nr	nr	nr
Tadiparthi s	JPRAS	2012	Akram 2013	28	nr	2.6/2.2 *	0.9	28 (12–43)
Rosen and Hartman	ASJ	2011	Akram 2013	34	3	nr	nr	34

Pechter	ASJ	2010	Akram 2013	35	nr	nr	nr	(3–30)
Brauman and Capocci	PRS	2009	Akram 2013	337	19	nr	nr	7 (0.1–111)
Batchvarova et al	PRS	2008	Akram 2013	52	nr	nr	nr	54 (6–132)
Dabb et al.	PRS	2004	Akram 2013, Hickey 2011	32	nr	nr	nr	>12
Cardenas Restrepo and Munoz Ahmed	PRS	2002	Akram 2013	42	nr	nr	nr	15 (6–24)
Ferreira et al.	Ann Plast Surg	2001	Akram 2013, Hickey 2011	56	nr	nr	nr	36
van Uchelen et al.	PRS	2001	Akram 2013, Hickey 2011	40	nr	nr	1.0–4.2	64 (32–109)
Nahas et al	PRS	2001	Akram 2013, Hickey 2011	20	nr	2.7 (1.6–3.9)	0	6
Nahas et al	PRS	2001	Akram 2013	88	nr	nr	NE	>3
Ramirez	PRS	2000	Akram 2013, Hickey 2011	10	nr	nr	nr	6
Zukowski	PRS	1998	Akram 2013	85	nr	nr	nr	nr
Asaadi	Ann Plast Surg	1994	Akram 2013, Hickey 2011	39	dnf	dnf	dnf	25
Ranney	S D J Med	1990	Akram 2013	1738	97	dnf	dnf	dnf
Williams et al	ASJ	2005	Hickey 2011	22	nr	nr	nr	12
Pollock et al	PRS	1999	Hickey 2011	65	nr	nr	nr	15 (3–96)
Nahas et al	Aesth Plast Surg	1997	Hickey 2011	14	0	2.7 (1.6–4.5)	0	6
Nahas et al	PRS	2005	Hickey 2011	12	0	2.4	0	81 (76–84)
Shirah et al	J Med Imp Surg	2016	Mommers 2017	216	nr	10 (7–13)		24
Privett et al	Hernia	2016	Mommers 2017	173	173	nr	nr	nr
Köckerling	Front i Surg	2016	Mommers 2017	40	40	nr	nr	1
Bellido et al	Hernia	2015	Mommers 2017	21	21	3.9 (< 4.4)	0.3	20
Emanuelsson	Surgery	2016	RCT	56	0	4.0 (2.0–7.0)	<2	12

* with/without previous abdominal surgery

nr = not reported, dnf = data not found

2.4.8.10 Complications of abdominoplasty

The complication rate of abdominoplasty is approximately 4% to 25% (Winocour et al., 2015). The complication rate increases when multiple procedures are performed at the same time (Staalesen et al., 2012). The most frequent complications are dehiscence, seroma, and cellulitis. These are characterized by prolonged post-operative wound healing but have minimal impact on the surgical outcome. Major complications rarely occur (Staalesen et al., 2012). Blood perfusion is crucial for normal wound healing (Mayr et al., 2004). Preserving adequate blood supply during surgery is essential (Figures 3-5).

2.5 PREGNANCY-RELATED LOW BACK PAIN

Pregnancy-related lumbopelvic pain is a common complaint. On the other hand, RD causes low back pain and motor control dysfunction in some individuals. The possible connection and causality of these phenomena is not known.

Pregnancy-related lumbopelvic pain is a broad concept and consists of pregnancy-related low back pain (PLBP), pregnancy-related pelvic girdle pain (PGP), and a combination of these (Wu et al., 2004). PLBP mirrors LBP in the non-pregnant population and is characterized as dull pain. Back pain before pregnancy is considered a risk factor for PLBP. For some individuals, back pain starts only after pregnancy (Wu et al., 2004). PLBP and PGP typically begin at the gestational week 18 and reach maximum between gestational week 24 and 36 (Gutke et al., 2018). PGP in pregnancy is estimated to affect about half of all pregnant women. Persistent low back pain after pregnancy has a prevalence rate of 5% to 7% (Wu et al., 2004). The underlying etiology of PLBP and PGP remains unknown.

3 AIMS OF THE STUDY

The aims of this study were to study the changes of the linea alba width after pregnancy, the consequences of abdominal rectus diastasis, and the surgical outcomes together with HRQoL following operative treatment.

The specific aims of this project were:

1) To assess the incidence of mild, moderate, and severe diastasis in fertile age Finnish female population and to analyze back pain and core instability in relation to RD severity
2) To assess if those having more lumbar back pain or core instability after pregnancy have wider inter rectus distance
3) To assess the objective results of operative treatment of RD with and without hernia
4) To assess patient-reported outcomes after surgery for RD or abdominal bulging

4 PATIENTS AND METHODS

4.1 STUDY PARTICIPANTS AND PATIENTS

This thesis consists of three patient/participant series; two studies were were prospective (Studies IV and II/III) and one was retrospective (Study I).

4.1.1 EPIDEMIOLOGICAL STUDIES (STUDIES II AND III)

In Study II, 933 women participating in the first pregnancy screening ultrasound in Helsinki University Hospital Department of Obstetrics and Gynecology between January 2018 to March 2019 were recruited. Each participant received study information and completed an electronic consent. The studies were approved by the Regional Ethics Review Board at Helsinki University Hospital. The exclusion criteria included inability to understand spoken and written Finnish or Swedish, BMI >28 kg/m^2 and if the questionnaire was completed after gestational week 20. The BMI limit of 28kg/m^2 was chosen as this is the upper limit for RD surgery in Jorvi Hospital. The linea alba width was measured by 20 midwives. Four hundred participants answered the questionnaire (Appendix 1), of which 303 met the inclusion criteria for symptom evaluation.

Study III was a continuation of Study II. Participants with increased subjective symptoms between questionnaires in Study II and a year after delivery were invited to a second inter-rectus diameter measurement together with motor control function test between November 2019 to March 2021. Thirty-six individuals scored at least five points, reflecting a substantial increase in symptoms in screening questions, Table 4. Of these, 14 participants were randomly recruited. Another 94 individuals scored the lowest possible points, suggesting no change in subjective wellbeing. Of these, 3 controls per case were recruited (altogether 42 controls). One participant dropped out; thus, the total number of controls was 41. All participants had at least 12 months since the last delivery.

Table 4 Screening questions in Study III and distribution of answers

		1 point	n=	2 points	n=	3 points	n=
Question 1	How well have you recovered from your previous pregnancy? Can you for instance perform the same sports as you did before pregnancy?	I have recovered well	143	I have recovered reasonably	114	I have recovered poorly	17
Question 2:	When you consider you current state, do you have more back problems (pain or discomfort) than you had before your pregnancy?	No	131	Slightly more	105	Considerably more	37

4.1.2 SURGICAL STUDIES (STUDY I AND IV)

In Study I, 37 consecutive patients with symptomatic RD with or without concomitant midline hernia were operated in Helsinki University Hospital Jorvi with a novel PSUM technique between June 2013 and April 2018. The data were analyzed retrospectively. The study was conducted in collaboration with the Department of Plastic Surgery and Abdominal Center. The study was a pilot study for an ongoing randomized controlled trial where PSUM and linea alba plication techniques were compared.

The prospective Study IV was performed in Laser Tilkka Hospital, Helsinki, Finland between May 2018 and May 2022. Forty-six consecutive patients with symptomatic RD were enrolled. Exclusion criteria were inability to understand spoken and written Finnish or Swedish. Smoking and excessive visceral obesity were contraindications for surgery. Each participant received study information and provided written consent. The studies were approved by the Regional Ethics Review Board at Helsinki University Hospital.

4.2 SURGICAL PROCEDURES (STUDIES I AND IV)

4.2.1 PSUM (STUDY I)

In Study I, linea alba restoration and RD repair was performed with the PSUM method. There were 25 patients (7 with hernias) in abdominoplasty group. A standard abdominoplasty with incision above the pubic hairline was performed in 14 cases. A modified abdominoplasty with Fleur-de-lis (Dellon,

1985) modification designed to remove excess, low-quality skin around the umbilicus by de-epithelization of stellar shape area was performed in 11 cases. In 12 patients, hernia repair was performed without abdominoplasty (Patch-group).

In abdominoplasty cases, the skin flaps were raised or the de-epithelization was performed first. In case of a hernia, the hernia sac content was either repositioned into the peritoneal cavity or resected. Repair of the RD was performed by suturing medial borders of the anterior rectus sheath from xiphoideum to symphysis with monofilament non-absorbable continuous suture. A partly absorbent, self-gripping polypropene mesh (ProgripR, Covidien) was tailored into a narrow 2-cm slice, which was implanted in an inlay fashion. A suture with non-absorbable nylon (Prolene 2-0, Ethicon) was performed over the mesh. The mesh thus stays in a tunnel formed by the linea alba plication (Figure 15). Every other or every third suture was reached through the mesh. At the base of the umbilicus stalk, the mesh was split into two to encircle the stalk. In a similar fashion, another slice of mesh was placed in the caudal end of RD plication below the umbilicus. After linea alba restoration, umbilical repositioning, resection of excess skin-subcutis, and layered closure of skin with absorbable sutures were performed. In the patch group, the tails of pre-peritoneally or intraperitoneally placed ventral patch was buried inside the plicated linea alba in a similar PSUM fashion using a small incision above the navel. Suprafascial level was not widely undermined in these cases.

Patients stayed in the hospital for 1–3 days after surgery. Drains were removed when there was <50 ml exudate per 24 hours. Patients were instructed to wear an elastic belt for 4 weeks and to avoid heavy lifting for 4–5 weeks.

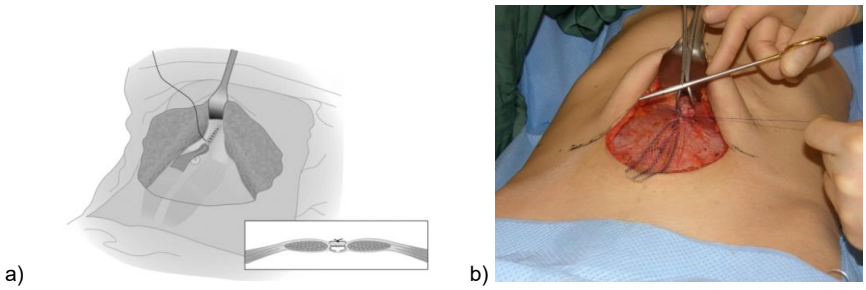


Figure 15 In the PSUM method, the medial borders of rectus sheath are plicated by running nylon suture. a) A narrow, partly absorbent, self-gripping polypropene mesh is placed inlay in the midline. b) Perioperative view.

4.2.2 HELP (STUDY IV)

In Stydy IV, all operations were performed by an experienced plastic surgeon (Hilkka Peltoniemi). The operative drawings were performed with the patient standing and sitting.

Hydrodissection and Epidural anesthesia for Lateral Plication (HELP) abdominoplasty is characterized by epidural anesthesia that allows patients to contract the abdominal muscles during the operation. The correct firmness of the fascia layer is practical to adjust in this way. An epidural catheter is placed at the level Th XII-X to reach an adequately high anesthesia. The catheter is left for the first night to secure efficient pain management, low opioid consumption, and to facilitate immediate mobilization.

The first step is infiltration of saline with adrenalin (1 mg/1000 ml) above the fascia layer (Figure 16). Hydrodissection reduces bleeding and facilitates dissection. The infiltration can be performed with Bodyjet or a simple 50-ml syringe with a blunt, long cannula.

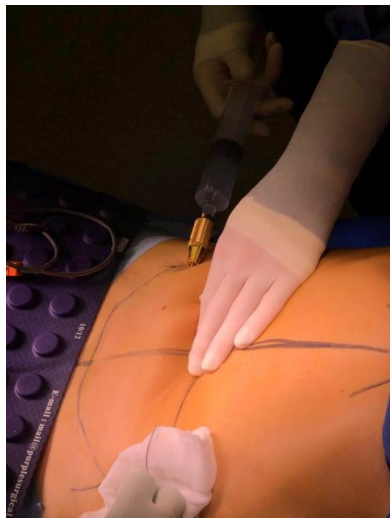
a)  b 

Figure 16 HELP-abdominoplasty technique details. a) Infiltration of adrenalin-saline. b) Wide dissection (rectus bellies clearly visible) with as little fat as possible left on top of the area to be plicated *(Photos courtesy o Hilkka Peltoniemi)*

The abdominal skin is lifted wide, as otherwise the skin does not fold appropriately after wide intake of the fascia layer (Figure 16b). Oval umbilicus is circumferentially dissected from the flap with a diameter of approximately 1 x 1.5 cm, leaving it attached to the abdomen by a short umbilical stalk with minimal fat.

If the patient has only a little excess skin and the umbilicus is not positioned low, mini-abdominoplasty with floating umbilicus can be utilized

(Wan et al., 2019b). In case of a hernia, the hernia sac or protruding preperitoneal fat is dissected from fascia opening and the hernia is either repositioned to the pre/intraperitoneal space or ligated. The fascia opening is closed with sutures. The laxity of the fascia layer is assessed and marked with a sterile marker over the rectus fascia (Figure 17a).

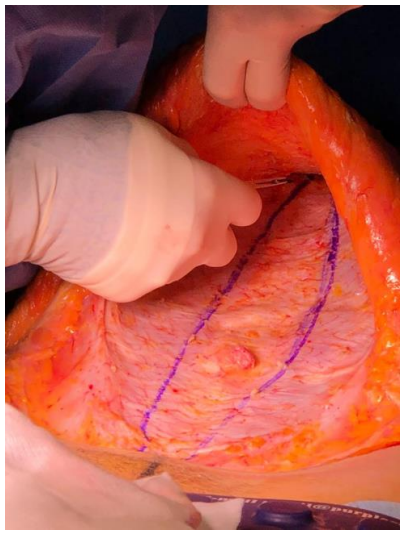
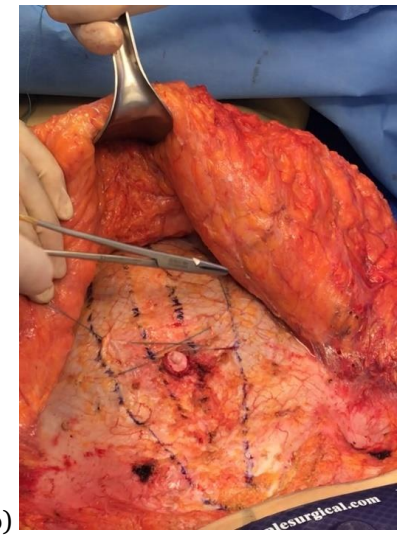
a)  b) 

Figure 17 HELP abdominoplasty technique details a) Plication estimation. b) First figure-of-eight suture with Ethibond 2. *(Photos courtesy of Hilkka Peltoniemi)*

Plication is performed in three layers. Non-absorbable multifilament (Ethibond 2, Ethicon) coronal plane figure-of-8 sutures are placed first (Figure 17b and 18 a). The vertical excess is controlled with figure-of-8 sutures; if there is more vertical excess, the figure-of-8 sutures are longer.

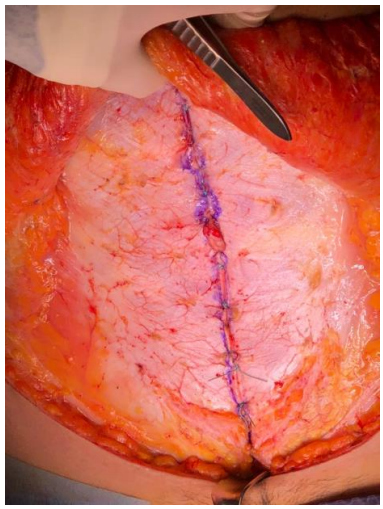
a)  b) 

Figure 18 HELP-abdominoplasty technique details. a) After all sutures of eight *(Photo courtesy of Hilkka Peltoniemi)*. b) Second layer of sutures with Quill 2 starts at level of the umbilicus.

After sutures-of-eight, two layers of barbed, thick, slowly absorbable running sutures are applied (Quill 2, Surgical Specialties) (Figure 18b). With barbed, Quill 2 the knots of non-absorbable Ethibond interrupted sutures are enclosed inside the plicated linea alba and the fascia layer is smooth (Figure 19a). This is important especially for thin patients who may feel knot granulomas in the fascia layer. Quill 2 suture has two needles. The suturing is started at umbilicus and the other arm of the suture heads into cranial direction. At xiphoideum, care must be taken to address the entire divarication and looseness to avoid creating a notch, as otherwise there may be post-operative local bulging in the epigastrium. After reaching the xiphoideum, the plication is shifted to caudal direction and a third layer of sutures is performed with the same Quill 2. Knots are not needed. The other arm of Quill 2 is reached from the umbilicus to symphysis and back again to cranial direction. Plication is performed as far beyond medial borders of RA as lateral laxity is present (minimum 0.5–1 cm).

a)  b) 

Figure 19 HELP-abdominoplasty technique details. a) Second layer buries all the knots of Ethibond 0 *(Photo courtesy or Hilkka Peltoniemi*). b) Tension stitch.

Under epidural anesthesia, the correct tension of the fascia layer can be tested when the patient lifts her head and stresses the abdominal wall.

Eight to twelve tension sutures are placed from subcutis to fascia to narrow the dead space and reduce seroma formation (Figure 19b).

The umbilicus is transposed with a short umbilical stalk into a new position in the abdominal wall (Correia et al., 2018). A new skin opening for the umbilicus is in the shape of an "I". HELP umbilicus is created with four absorbable, multifilament 2-0 three-point sutures through plicated fascia layer, umbilical stalk, and dermis of the new skin opening that is prepared with removal of the fat (Figure 20a). Three-point sutures are placed in four directions to anchor the umbilical scar deep to fascia (clock 12, 3, 6, and 9).

a)  b) 

Figure 20 HELP-abdominoplasty technique details. a) Three-point suture creates natural umbilicus with scar hidden deep. b) Before excision of extra tissue *(Photos courtesy of Hilkka Peltoniemi)*.

Later, the skin edges of the umbilical stalk and the new opening are adjusted with simple absorbable, monofilament sutures. With wide RD, it is typical that RD has displaced the subcutis of the original cranial side of the umbilicus and the dermis is directly in contact with the fascia layer (Figure 20b). If this is the case, a skin-subcutis flap can be de-epithelized from above the symphysis (from the area to be excised) to augment this lack of tissue (Figure 21).

Figure 21 HELP-abdominoplasty technique detail. De-epithelized flap to augment the original supraumbilical area.

No suction drains are routinely left. The bikini line is sutured in layers as usual. Operative time is between 120–180 minutes depending on patient size, presence of hernia, and amount of excess skin. An abdominal elastic band is positioned for 2–4 weeks 24 h/day. The band is placed during the daytime for 2–4 weeks after this period. Discharge is on the first post-operative day and follow up is performed at 2 weeks and 9–12 months post-operatively. No anticoagulation is used unless the patient has predisposing factors for deep venous thrombosis. Patients should wear anti-embolic stockings until they are properly mobilized.

4.3 OBJECTIVE OUTCOMES

4.3.1 IMAGING (STUDIES I, II, II AND IV)

In this thesis, all radiological examinations measuring RD were performed using US. In Study I, US was performed only for clinical purposes. If a patient suspected a recurrent RD or hernia, she was called back for clinical and US examination.

In Study II, 20 midwives performing pregnancy screening US measured the width of the linea alba in women, who they estimated to be of normal weight.

To standardize measurements, a hands-on workshop was organized with an instructing radiologist. In addition, a how-to video was provided and every screening unit room was supplied with an infographics sheet. The width was recorded in supine position. One representative measurement was taken 3 cm above the umbilicus using a high-end US machine and a high-resolution linear array transducer. The focus and depth were adjusted as usual.

In Study III, two physiotherapists were trained with the same protocol as the midwives in Study II to measure linea alba width in a standard manner using a transportable high-end US advice. The physiotherapists were blinded to which study group the participant belonged to and on the IRD in the first measurement.

In Study IV, US was performed by R.T. in supine position and with relaxed abdominal wall, using a high-end US machine (Sonosite LX) and a high-resolution linear array transducer L15-4 (Fujifilm). US follow up was offered to every patient in Study IV. Four patients were not reached via email or phone and 6 patients were unable to attend (long distance or scheduling problems), thus 36/46 (78%) patients were available for measurement.

4.3.2 FUNCTIONAL TESTS (STUDIES III AND IV)

In Study III, two physiotherapists conducted video recorded motor-control tests. Three tests assessing motor control of lumbopelvic spine were chosen in collaboration with Department of Physical and Rehabilitation Medicine. The tests have acceptable interrater reliability (Luomajoki et al., 2007). With the tests, patients can be reliably stratified as asymptomatic or having either acute and or chronic low back pain.
(Luomajoki et al., 2008; Meier et al., 2021). Waiter's bow is a flexion control test of the lumbopelvic spine. Pelvic tilt assesses extension control. Postural and balance control is tested with one-leg stance test. In addition, active straight leg (ASLR) was recorded (J. M. Mens et al., 1999; J. M. A. Mens et al., 2001), which assesses lumbar spine stability and abdominal bracing ability. An abnormal test is positive, meaning that external compression of the hip makes lifting the straight leg easier. Normal performance is negative, as external compression of the hip does not have an impact on lifting the straight leg.

In addition to established motor-control tests, a sit-up test was performed with a simple version where arms are crossed in front of the chest and elbows touch the knees in an upright position. The ease or difficulty in laying down or standing up from laying position was evaluated. In Study III, all tests were video recorded and analyzed blindly by an independent clinical test specialist (J.M) who did not know the exposure status of the participants.

In Study IV, a sit-up test and ASLR were recorded pre- and post-operatively.

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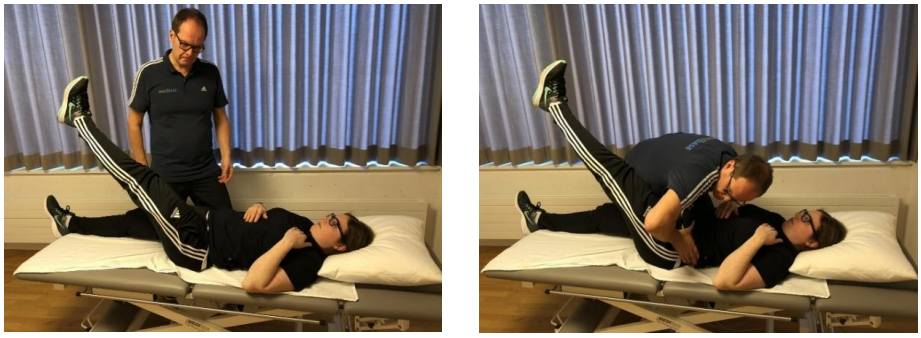

g h

Figure 22 Motor-control tests. a) Correct execution of Waiter's bow. b) Incorrect execution of Waiter's bow. c) Correct execution of pelvic tilt. d) Incorrect execution of pelvic tilt. e) Correct execution of one-leg stance. f) Incorrect execution of one-leg stance. g) Active straight-leg raise without compression. h) Active straight-leg raise with compression (*Photos courtesy of Hannu Luomajoki, Liikkeen ja liikekontrollin häiriöt. 2. Painos. VK Kustannus).*

4.4 PATIENT/PARTICIPANT-REPORTED OUTCOMES

In modern medicine, the patient perspective on treatment and care measured with an established instrument is an equal endpoint together with objective endpoints (Gill, 1994). In Studies II, III, and IV, an electronic questionnaire link was sent the email address provided by the participant. The questionnaire was run on a server owned by the University of Helsinki.

4.4.1 HEALTH RELATED QUALITY OF LIFE SURVEY RAND-36

HRQoL is a multi-dimensional tool that includes domains related to physical, mental, emotional, and social functioning that are used to examine the impact of health status on quality of life (Staquet et al., 1996). RAND-36 is a widely utilized HRQoL survey instrument (Hays et al., 1993). RAND-36 was chosen as there is an open-access Finnish version of the questionnaire.

4.4.2 QUESTIONNAIRES

4.4.2.1 Study I

Patient records were reviewed and symptoms for indication to surgery were identified. Patients were retrospectively interviewed and their perception on the effect of the surgery on LBP and motor control were asked on a trinomial grading (did the operation reduce the symptoms or not or "cannot say").

4.4.2.2 Study II and III

Surveys were identical and included the validated HRQoL tool RAND-36 (Aalto et al., 1999; Hays & Morales, 2001). The questionnaire also included Oswestry 2.0 validated low-back disability index (Pekkanen et al., 2011). In addition to previously described established questionnaires, sociodemographic and clinical questions with variables on sports activity and satisfaction of abdominal-wall contour were included. The questionnaire in detail is presented in the Appendix 1.

4.4.2.3 Study IV

The questionnaire used in this study was mostly analogous to Studies II and III with the exception of an additional supplementary portion of diastasis-related questions on symptoms. The Study IV survey did not include Oswestry 2.0 for the sake of brevity. The questionnaire in detail is presented in the Appendix 2.

4.5 STATISTICAL ANALYSIS

4.5.1 STUDY I

Descriptive statistics were reported as percentages.

4.5.2 STUDY II

Statistical analyses were performed by a statistician (T.P) using NCSS 12 Statistical Software. The alpha level for all statistical tests was set 0.05 (P-value). Equal-Variance T-Test was used to compare numerical variables when distributions were approximately normal. Aspin-Welch Unequal-Variance T-Test was also utilized with unequal sample sizes. Mann-Whitney U-Test was used when the variable distributions were non-normal. The Pearson χ^2 test was used to assess the linea alba width and previous cesarean sections and pregnancies. The correlation between linea alba width and back pain was analyzed with Pearson linear correlation test.

4.5.3 STUDY III

Equal-Variance T-Test was used to compare numerical variables when distributions were approximately normal. Mann-Whitney U-Test was used when the variable distributions were non-normal. Fisher's exact test was used to assess motor control dysfunction test differences between cases and controls. The alpha level for all statistical tests was set to 0.05.

4.5.4 STUDY IV

Wilcoxon Signed-Rank Test was used to compare numerical variables as distributions were approximately normal.

5 RESULTS

5.1 EPIDEMIOLOGICAL STUDIES (STUDIES II AND III)

5.1.1 PARTICIPANT CHARACTERISTICS (STUDY II AND III)

In study II, 933 women were recruited and 400 answered the questionnaire; 303 women met the inclusion criteria for symptom evaluation. A total of 131 women were excluded for the following reasons: 1 was missing ID information, 60 had BMI >28 kg/m², 70 answered the questionnaire after gestational week 20 + 6. The median answering timing was gestational week 15 ± 2.1. There were no relevant differences in IRD, or previous pregnancies between those who answered the questionnaire and those who did not (Table 5). Those who answered were a bit older.

Table 5 Characteristics of those who answered the questionnaire and those who did not in Study II.

Participants	answered, n=397	did not answer n=536	test	p-value
Age	31.8	30.9	Aspin-Welch Unequal-Variance T-Test	<0.05
IRD, mm	21.6	21.0	Aspin-Welch Unequal-Variance T-Test	0.27
Previous pregnancies, average	0.70	0.80	Mann-Whitney U	0.14

5.1.2 EPIDEMIOLOGY OF IRD (STUDY II)

The distribution of IRD observations in the entire Study II cohort, including those who did not answer the questionnaire, is shown in Figure 23.

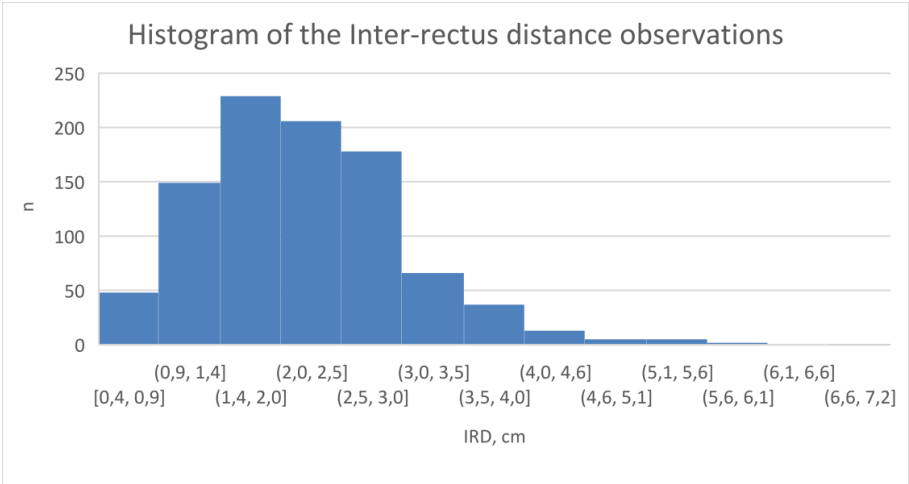

Figure 23 Study II. Histogram of the inter-rectus distance observations.

The mean linea alba width with standard deviation among nulliparous women was 1.81 ± 0.72 cm. The average linea alba width was 2.36 ± 0.83 cm after one previous pregnancy and 2.55±1.09 cm after ≥2 pregnancies (Figure 24). There was a positive correlation between previous pregnancies and increased linea alba width ($p<0.05$).

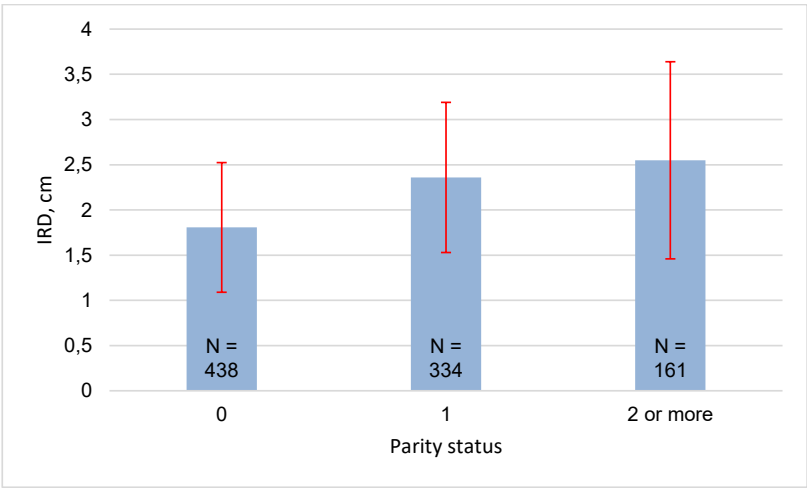

Figure 24 Study II. Inter-rectus distance as a function of number of pregnancies.

5.1.3 CORRELATION OF IRD AND RD-RELATED SYMPTOMS (STUDY II)

We did not identify a threshold level of linea alba width that would predispose to RD-related symptoms in this study (Figure 25 and 26).

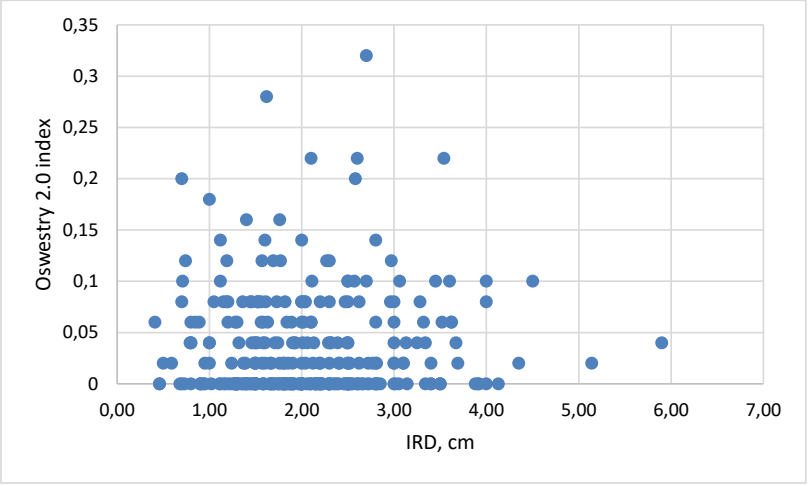

Figure 25 Study II. Correlation of Oswestry disability index and IRD.

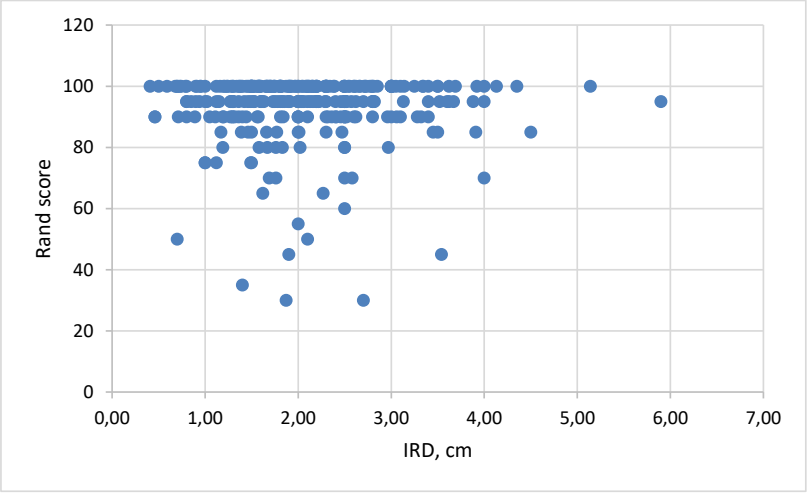

Figure 26 Study II. Correlation of HRQoL RAND-36 domain physical functioning and IRD.

As wider IRD observations were rare in the cohort, categorizing was performed with a cutoff value of 3 cm, which is the lower limit for moderate diastasis. There were 37 observations of ≥3 cm. Background variables are shown in Table 6. The only correlation observed was with previous pregnancies.

Table 6 Study II background variables and risk factors

	IRD <3 cm		IRD >3 cm			
	n, given answers	mean	n, given answers	mean	test	p-value
Age	266	31.5	37	32.2	Equal Variance T-Test	0.39
BMI (kg/m^2)	266	22.9	37	23.5	Equal Variance T-Test	0.16
Weight change in present pregnancy, kg	266	2.8	37	3.6	Equal Variance T-Test	0.17
Weight change in previous pregnancies, kg	127	13.4	33	13.8	Equal Variance T-Test	0.77
Sport habits	265	3.1	37	3.2	Equal Variance T-Test	0.85
Largest baby at birth, kg	106	3.5	29	3.6	Equal Variance T-Test	0.24
N of previous pregnancies 0/1/≥2	139/91/36		5/25/7		Pearson's χ^2	<0.05
Cesarian sections	16		2		Pearson's χ^2	0.88

5.1.4 SYMPTOMS RELATED TO RD AFTER PREGNANCY (STUDY III)

Cases reported increased back pain or core instability a year after pregnancy; controls reported no change in their bodily experience. Cases were defined by screening questions. The screening question results were consistent with HRQoL scores. As expected, HRQoL scores of cases decreased between datapoints, reflecting poorer health. After the index pregnancy, the HRQoL domains (physical functioning, bodily pain, and general health) scored lower than the population norm in the case group. In contrast, the scores of controls increased slightly between datapoints and were above the population norm at the time of the second questionnaire. The age-matched population mean values are from the Finnish validated version of the survey (Aalto et al., 1999).

Cases had had more pregnancies (mean 2.5 ±0.7) than controls (2.0 ± 0.7, $p<0.05$). The mean IRD at the baseline measurement was 2.45 ± 1.01 cm in the case group and 2.09 ± 1.03 cm in the control group ($p=0.72$). At the second

measurement a year after index pregnancy, IRD was 3.45 ± 0.90 cm in the case group and 2.40 ± 0.79 cm in the control group ($p<0.05$).

5.1.5 MOTOR CONTROL TESTS (STUDY III)

There was no correlation between symptoms and movement-control tests (Waiter's bow, pelvic tilt, or one-leg stand). A positive correlation was seen in laying down observations, with cases having more incorrect executions ($p=0.008$). As cases were defined with back pain or motor-control dysfunction, we also analyzed the motor-control tests in relation with self-reported movement control dysfunction only having the same results. There was a correlation with the sit-up test, as the mean number of sit ups was 4.7±4.2 in the symptomatic case group and 8.2±3.9 in the control group ($p<0.05$).

5.2 SURGICAL STUDIES (STUDIES I AND IV)

5.2.1 PATIENT CHARACTERISTICS

Patient demographic and clinical characteristics (Studies I and IV) shown listed in Table 7.

Table 7 Patient characteristics in Studies I and IV

	Study I	Study IV
Age, mean (range), years	36.0 (26.5–45.7)	40.5 (32.1–54.9)
Parity, mean (range)	2.3 (1–4)	2 (1–4)
Gemini pregnancies, n (%)	3/37 (8)	12/46 (26)
Cesarian sections, n (%)	15/37(40)	20/46 (43)
BMI, mean (range), kg/m^2	23.7 (19.1–33.1)	24.0 (18.8–33.3)
IRD, mean (range), cm	5.2 (4.0–9.0)	4.6 (2.3–9.0)
mild RD (>2 to ≤3 cm), n (%)	0	2/46 (4)
moderate RD (>3 to ≤5 cm), n (%)	8/37 (22)	30/46 (65)
severe RD (>5 cm), n (%)	29/37 (78)	14/46 (31)
Total plicated fascia distance *, mean (range), cm		7.8 (6.0–13.5)
Hernia		
Umbilical hernia, n (%)	16/37 (43)	11/46 (24)
Fascia defect, mean (range), mm	dnf	11.3 (5–20)
Epigastric hernia, n (%)	3/37 (8)	6/46 (13)

Fascia defect, mean (range), mm	dnf	12.5 (5–20)

*total plicated fascia includes RD and the excess lateral fascia

dnf, data not found

There were 2 patients with mild diastasis (2.1 and 2.5 cm, respectively), but overall plication in these patients addressing lateral laxity was 6.5 and 9.0 cm, respectively.

5.2.2 INDICATIONS FOR SURGERY

In Studies I and IV, patients had either back pain or core instability that was not responsive to physiotherapy. Core instability manifested with difficulties in sports activity (such as skiing, riding, yoga) or everyday life (such as lifting, standing, or walking long periods). The typical experience was a feeling that the body does not have the necessary support and control was lost or significantly reduced. Obesity and smoking were contraindications in both studies.

5.2.3 OBJECTIVE OUTCOMES AFTER SURGERY

5.2.3.1 Ultrasound (Study IV)

In Study I, the stability of RD repair was manually assessed post-operatively. An US was performed when recurrence was suspected. There was one RD recurrence during the follow-up period. With this patient, RD-related symptoms, back pain, and weakness in the abdominal muscles also relapsed 18 months post-operatively. The perioperative BMI of the patient was >33 kg/m^2 and RD was 9.0 cm. The patient gained weight post-operatively; at the 26-month follow-up visit BMI was 35 kg/m^2 and IRD was 4.0 cm as measured with US.

In Study IV, US follow up was performed a median of 26.6 (range 8–46) months post-operatively. The 8-month assessment was an outlier, and all other assessments were performed after a minimum of 1 year of follow up. The COVID-19 pandemic caused a delay in assessments. The rectus bellies were from 0 to 5 mm apart from each other (mean 1.6 mm). Sixteen patients had a perioperative midline hernia and US revealed no hernia recurrences. An US example is shown in Figure 27.

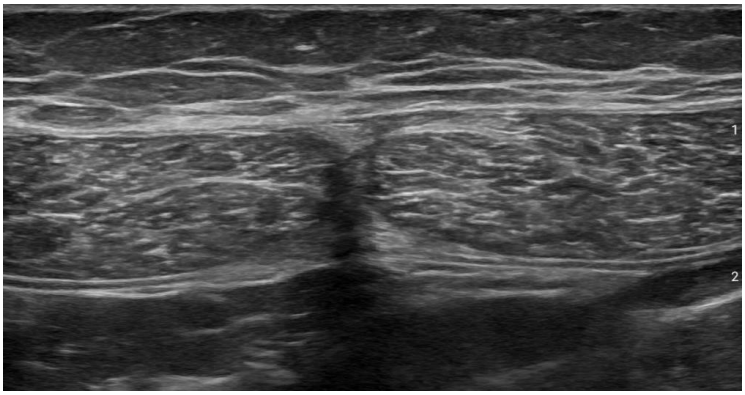

Figure 27 Post-operative ultrasound after HELP-abdominoplasty with rectus bellies contacting each other.

5.2.3.2 Functional tests (Study IV)

Most participants were unable to perform sit ups pre-operatively; median performance was 0. The sport habits remained the same pre- and post-operatively. A year after HELP-abdominoplasty, all patients except one (whose back had been operated before) were able to perform sit-ups again; median performance was 11 (range 7–18). Post-operative data on sit-ups were missing from 2 participants. ASLR was positive (abnormal) in 45/46 patients pre-operatively. Two of forty-six patients had a positive (abnormal) result a year after HELP abdominoplasty and extensive fascia plication. Patients were not informed of the interpretation of ASLR or performance on the sit-up test in advance.

5.2.4 PATIENT-REPORTED OUTCOMES AFTER SURGERY

5.2.4.1 HRQoL RAND-36 (Study IV)

Results of surgery on HRQoL and age-matched reference scores from Study IV are presented in Table 8 and Figure 28. The mean pre-operative values were below the age-matched reference values but increased beyond the corresponding values 1-year post-operatively.

Table 8 Study IV RAND-36 HRQoL Domain Scores pre-operatively and post-operatively with Standard error (SE).

Health-Related Quality of Life Domains	Pre-operative	Post-operative	35-44 population mean *	p-value**
Physical functioning	73.8 ± 16.0	96.6 ± 5.5	92.1	<0.05
General health	67.8 ± 21.6	81.3 ± 17.3	70.3	<0.05
Physical role functioning	68.5 ± 36.7	96.2 ± 15.8	83.2	<0.05
Bodily pain	53.3 ± 21.6	88.0 ± 14.0	79.2	<0.05
Emotional role functioning	75.4 ± 38.1	87.0 ± 24.8	79.1	0.12
Social functioning	71.7 ± 24.6	93.2 ± 13.6	81.6	<0.05
Vitality	42.8 ± 18.0	56.5 ± 13.9	60.8	<0.05
Mental health	69.7 ± 17.6	78.7 ± 13.9	70.8	<0.05

The maximum score is 100, indicating the highest possible subjective.health perception

* Normative values of age-matched population from Aalto et al.

p**, Probability level

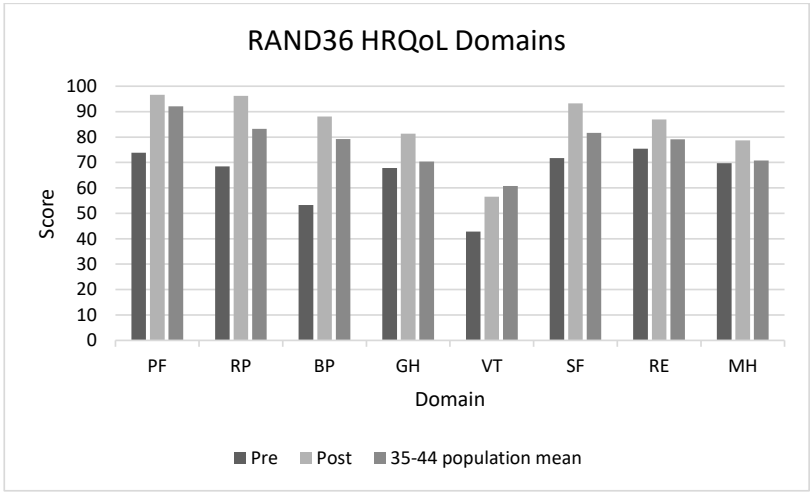

Figure 28 Study IV. HRQoL RAND-36 HRQoL Domain Scores pre-operatively and post-operatively. The maximum score is 100, indicating the highest possible subjective health perception. Normative values of age-matched population from Aalto et al. PF=Physical functioning, RP=Physical role functioning, BP=Bodily pain, GH=General health, VT=Vitality, SF=Social functioning, RE=Emotional role functioning, MH=Mental health.

5.2.4.2 RD-related symptoms

In Study I, patients were asked if they have LBP or core instability symptoms pre-operatively. If such symptoms were present, they were asked to describe the perceived symptoms at the time of data collection. After surgery, back pain was reduced in 16 of 20 patients who had back pain before surgery. For patients with core instability, 26 of 27 had symptom relief post-operatively (Figure 29).

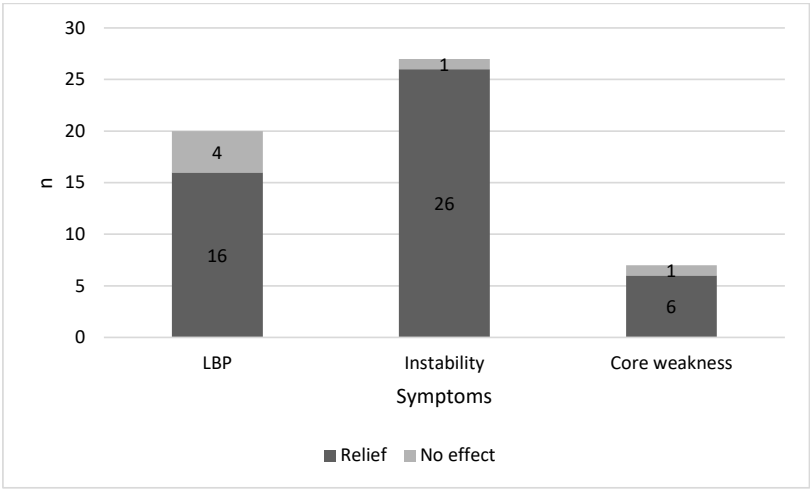

Figure 29 Study I. Retrospective patient-reported outcomes post-operatively versus pre-operatively.

The results of surgery in Study IV on patient-reported RD-related symptoms are summarized in Table 9. There was a significant improvement after surgery on the ability to keep posture when standing and when bending over (for example while lifting children), on durability of back muscles when standing long periods, and on pain reduction in lumbar region in the morning. Difficulties when standing up from lying down, the effort required to control the abdomen from not bulging, and disturbing bulging after eating were reduced.

Table 9 Study IV symptom questionnaire and mean answers pre- and post-operatively with standard deviation (SD).

Q		Pre-operative, mean ± SD	Post-operative, mean ± SD	Probability (Wilcoxon)
1	How often do you exercise hard enough to be out of breath or sweating?	2.7 ± 0.9	2.7 ± 0.9	0.89
2	How often does urine leak when you are physically active, including running or sneezing?	*	*	*
3	How often does urine leak when you are physically mildly active, including walking or standing?	*	*	*
4	Overall, does leaking of urine interfere with your life?	*	*	*
5	Select the number of protective garments for urine leakage you use per day	*	*	*
	Incontinence score = Questions 2-5 points summed	1.4 ± 1.8	0.7 ± 0.8	<0.05
6	Are you satisfied with the contour of your abdomen?	4.7 ± 0.6	1.6 ± 0.8	<0.05
7	During the last month how much have you had problems in maintaining your posture?	1.9 ± 0.7	4.4 ± 0.6	<0.05
8	During the last month how much have you had fatigue or back pain when standing for long periods?	1.9 ± 0.7	4.4 ± 0.6	<0.05
9	During the last month how much have you had fatigue or back pain when bending over long periods, including lifting a child?	2.0 ± 0.9	4.4 ± 0.7	<0.05
10	During the last month how much have you had pain in lumbar back after waking up?	2.3 ± 1.2	4.7 ± 0.7	<0.05
11	During the last month how much have you been struggling when standing up from a lying position?	2.0 ± 1.2	4.7 ± 0.6	<0.05
12	During the last month has your abdomen been bulging?	1.6 ± 1.0	4.8 ± 0.5	<0.05
13	During the last month how much has your abdomen been bulging after eating?	1.9 ± 1.0	4.5 ± 0.7	<0.05
14	Have you had lumbar pain during the last 12 months?	3.0 ± 0.9	1.3 ± 1.1	<0.05
15	Have you had lumbar pain during the last 30 days?	2.1 ± 0.8	0.5 ± 0.7	<0.05
16	On VAS scale from 0-10, how intense is the lumbar pain at the moment?	4.5 ± 2.3	0.5 ± 0.9	<0.05

*Analyzed as a component of the incontinence score
Scoring algorithm is provided in the Appendix.

5.2.4.3 Aesthetic results

In Study I, 4 of 12 patients were unsatisfied with the aesthetic results, as a surplus of skin was clustered in the midline in the Ventral patch group. Abdominoplasty was subsequently performed on two of these patients (Figure 30.)

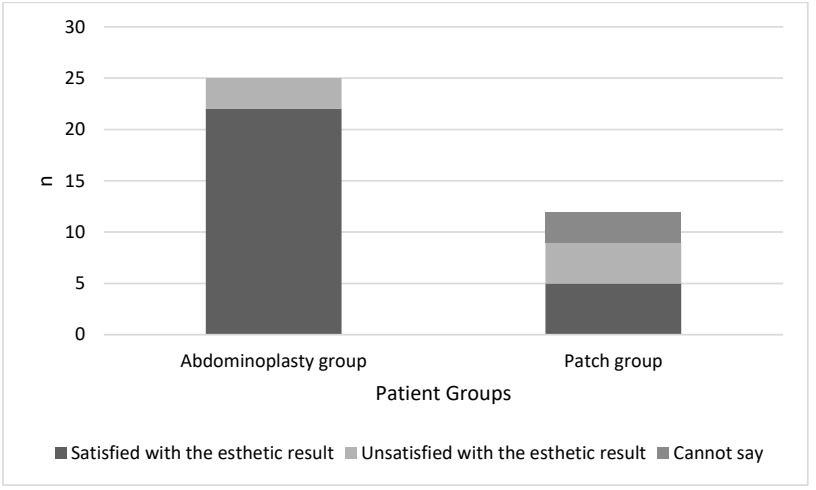

Figure 30 Study I. Retrospective patient-reported satisfaction on aesthetic results.

In Study IV, patients were asked about their satisfaction on their abdomen on a Likert scale (Norman, 2010) . Pre- and post-operative mean answers were 1.6±0.8 and 4.7±0.6, respectively (Figure 31).

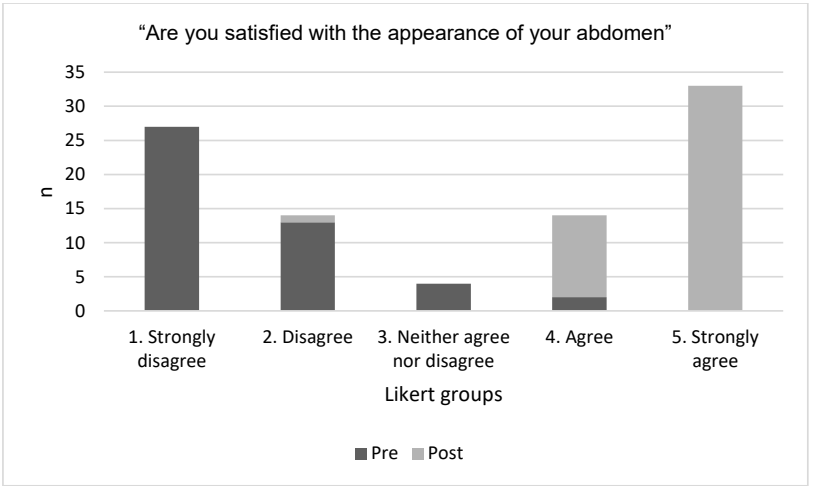

Figure 31 Study IV. Patient-reported satisfaction on abdomen contour scored on a Likert Scale.

5.2.5 COMPLICATIONS

Complications were classified according to Clavien-Dindo classification (Table 10). (Dindo et al., 2004). In Study I, minor dog ear removals were performed under local anesthesia for four of the abdominoplasty patients and were not classified as complications.

In Study IV, 1 patient had local pain 4 weeks post-operatively that was likely caused by a tension suture. The pain ceased with blunt-needle manipulation under local anesthesia in the fascia layer, which sought to cut the suture causing pain.

Table 10 Complications in operative studies.

Complications	Study I (n=37)	Study IV (n=46)
Clavien-Dindo Class I		
Seroma (no intervention)	1	1
Local infection, wound opened bed side		1
Mild umbilical cellulitis, antibacterial liniment used		1
Local pain, needle manipulation		1
Clavien-Dindo Class II		
Local infection, oral antibiotic	2	1
Clavien-Dindo Class III		
Hematoma evacuation reoperation	2	
Total complication rate	13.5%	9.1%

6 DISCUSSION

6.1 GENERAL CONSIDERATIONS

RD is a common complaint. Different symptoms, such as back pain, core instability and bulging contour of the abdomen are associated with RD. There are minimal data on RD. For instance, it is unclear how pregnancy alters the IRD and when the alteration has an impact. It is also unclear which symptoms can be addressed with operative treatment and what is the evidence base for patient selection for surgery. These topics were investigated in detail in this thesis.

The anterior abdominal wall biomechanically influences the movements and stability of the lumbar spine and abdominal strength (Gunnarsson et al., 2015; Hodges et al., 2005). The linea alba is a tendon-like structure that should transfer force efficiently. Physiotherapy is the primary intervention for RD and loose tone of the anterior abdominal wall (Hernández-Granados et al., 2021). For some individuals, physiotherapy alone is insufficient and surgery should be considered. RD concerns two surgical specialties, namely general and hernia surgery as well as plastic and reconstructive surgery. Both specialties have their own traditions and approach to treatment.

The quality of linea alba in the RD patient is often poor, as the tissue is overstretched, thin, and prone to hernias. Mesh is recommended for umbilical and midline hernia repair in association with RD (Bittner et al., 2019; Kohler et al., 2015; Kulacoglu, 2018) and when IRD is >5 cm (Fiori et al., 2020; Nahabedian, 2018; Ranney, 1990). Although mesh repair is established and safe, the use of sublay mesh necessitates opening the retro-muscular space, thus increasing the invasiveness of the procedure. The PSUM approach, which is presented here, offers a minimally invasive mesh technique without opening the retro-rectus space. Other new minimally invasive techniques for hernia repair and for restoration of linea alba have been published that utilize mesh (Table 2). However, one disadvantage of minimally invasive techniques is that the generated discrepancy of preserved skin and subcutis and reduced fascia area is not addressed. With abdominoplasty, the amount of skin and subcutis can be adjusted to the area of the fascia layer. Wide fascia plication necessitates wide dissection for the skin to fold without bagging. This can be laborious with endoscopic techniques.

The concept of not using a mesh is based on the concept of restoring the entire damaged RD and leaving the stretched linea alba to reinforce the suture underneath the suture line. A slim patient with post-partum RD has an abundancy of fascia layer and no excess content in the intraperitoneal cavity to stress the abdominal wall that would predispose to recurrence of the midline hernia, in contrast to an obese patient. Hernia recurrences were not observed in Studies I or IV. Although the techniques used were different, the

principle of restoring the entire damaged midline and not performing only hernioplasty was similar. These results support the need for holistic midline restoration and not only hernia repair in the case of combined RD and hernia.

RD surgery is generally considered if the individual does not plan to have more children. Patients frequently ask what happens if they do get pregnant after surgery. Abdominoplasty after massive weight loss is safe for the child and mother (Pajula et al., 2021). In patients with massive weight loss, RD does not always need to be corrected. There are some case reports of pregnancy after diastasis repair. One was suture repaired and there was no RD recurrence after pregnancy verified with CT scan (F. Nahas, 2002). One patient became pregnant 2 months (Borman, 2002) and another 5 years (Menz, 1996) after abdominoplasty. Linea alba was plicated in both cases, but IRD was not reported. The authors did not observe recurrence of RD. There was also a case of pregnancy after sublay mesh implantation and restoration of 4.5-cm diastasis. There was no RD recurrence post-partum verified with US ultrasound. The precise IRD was not reported (Faessen et al., 2020). None of the case reports revealed adverse effects to the baby or delivery. In Study I there was one post-surgery pregnancy. A patient became pregnant 2 years after PSUM abdominoplasty. A caesarean section was performed at gestational week 38. RD repair was stable (IRD <2 cm) 10 months after pregnancy measured with US and the patient reported no recurrence of low back pain.

Lateral laxity has gained only minimal attention in the literature (Brauman, 2008; F. X. Nahas, 2001; Toranto, 1990). According to this thesis, lateral laxity is a dimension of RD and some patients benefit from addressing it during operation by extending the plication beyond the lateral borders of RA. If only linea alba is corrected, there is still bulging of the abdomen in some cases.

6.2 EPIDEMIOLOGY

In Study II, the finding of a mean IRD of 2.4 cm in parous females challenges the dogma of linea alba being normal only up to 2 cm. The upper limit to IRD that is considered normal may be higher than that stated thus far. A recent cross-sectional study supports this concept and concluded that the definition of RD may need to be revised (Kaufmann et al., 2021).

The increased demand for operative treatment requires further studies to identify individuals who are most likely to benefit from invasive treatment. Mild and moderate diastasis alone do not seem to predispose to diastasis-related difficulties and therefore these conditions alone may not be an indication for surgery. In Finland, the current indication for RD surgery in public health care is ≥3 cm, which according to Study II is close to average. According to operative Studies I and IV, patients with symptomatic severe or nearly severe (mean IRD 5.2 cm and 4.6 cm in Studies I and IV, respectively) benefit from surgery. This thesis supports the treatment criteria provided by

The Swedish Guideline on RD management: "*The largest width of the diastasis should be at least 5 cm before surgical treatment is considered. In case of pronounced abdominal bulging or concomitant ventral hernia, surgery may be considered in patients with a smaller diastasis"* (Carlstedt et al., 2020).

6.3 OPERATIVE OUTCOMES

6.3.1 OBJECTIVE OUTCOMES (STUDY IV)

There are limited data of the objective results of RD repair. Previous studies reported RD plication stability mostly as surgeon-reported outcomes, which are prone to bias. Study IV reported objective post-operative US measurements. Rectus bellies were closer than in previous studies (Mestak et al., 2012; Swedenhammar et al., 2021). Addressing lateral laxity in an aggressive manner may explain at least some of the differences between Study IV and others. Addressing lateral laxity requires more data before final conclusions can be made. There are no long-term results on lateral laxity repair.

The inability of the patients to perform sit-ups in Study IV was surprisingly consistent. Even a dancer and a former national-level athlete were unable to adapt to RD and loose abdominal wall pre-operatively and were unable to perform sit-ups. Without any attempt to elevate the score, the results were significantly better post-operatively. ASLR was also demonstrative in this series. These are interesting findings for future studies. The sit-up test and ASLR can be evaluated in an outpatient clinic if their clinical importance is considered high.

6.3.2 SUBJECTIVE OUTCOMES (STUDIES I AND IV)

There is some evidence that RD repair has a positive impact on the individual's wellbeing. In previous studies, established questionnaires were seldom used and most of the evidence is retrospective in nature (Akram & Matzen, 2014; Brauman, 2008; ElHawary et al., 2020; Hickey et al., 2011; Toranto, 1990). One exception is the Emanuelsson et al study, where there was a significant improvement in perceived pain according to the scales of the ventral hernia pain and SF-36 HRQoL questionnaires at 1-year follow up (Emanuelsson et al., 2016). The results of Study IV are consistent with that of the Emanuelsson et al study. There was a significant increase in HRQoL scores in RAND-36 domains between datapoints in physical functioning (PF), bodily pain (BP), general health (GH), social functioning (SF), and vitality (VT). Although the questionnaires were not identical, the trend was similar. RD repair is not only an aesthetic but also a reconstructive surgery for some individuals.

In the retrospective analysis of Study I, patient satisfaction with surgery was high and consistent with previous studies (Asaadi & Haramis, 1994; Batchvarova et al., 2008; Brauman & Capocci, 2009; Dabb et al., 2004; Kanjoor & Singh, 2012; F. X. Nahas, 2001; O. M. Ramirez, 2000; Ranney, 1990; Restrepo & Ahmed, 2002).

In Study IV, there were statistically significant differences in all measured clinical symptoms before and after surgery. These improvements in wellbeing can have a major impact on a person's life. Study IV suggests that the following concerns can be addressed with HELP technique: durability of back muscles when standing and walking long periods, lumbar pain, difficulties when standing up from lying down, the need to pay attention to prevent abdominal bulging, and disturbing bulging after eating.

6.4 COMPLICATIONS

The post-operative complications in Study I and IV were minor and consistent with previous studies (Staalesen et al., 2012). In Study IV, no seromas requiring interventions were observed, although drains were not used. Tension sutures are a possible explanation. Patients were also of normal weight. Patients were mobilized quickly, and pain management was good with an epidural catheter left in for the first night. Deep venous thrombosis was not observed even without use of anticoagulation.

In the Patch group, 4 of 12 patients were unsatisfied with the aesthetic result. This was consistent with previous studies. The limitation of minimally invasive techniques is the surplus of soft tissue clustered at the midline because of the RD plication; the wider the ARD is, the more there is excess skin (Palanivelu et al., 2009; Siddiky & Kapadia, 2010).

6.5 STRENGHTS

Studies II-IV were prospective in nature. Study II is the largest epidemiological study on normative values of linea alba in a female population. Electronic questionnaires were used in Studies II-IV. Electronic questionnaires minimize human error and are less labor intensive in a large trial in the data integration phase. Study IV is one of the few prospective studies focused on operative treatment of RD with HRQoL data and objective imaging. Lateral laxity, discussed in Study IV, is an unreported dimension of RD surgery.

6.6 LIMITATIONS

Study I was small and retrospective. The primary goal of this study was to present the PSUM method as a preliminary case series for a RCT (ClinicalTrials.gov NCT03509376). In Study II, there was a risk of selection bias as midwives performed the measurements in addition to their normal work. Difficult cases may have had an increased risk not to be performed. Pregnancy, although in first trimester, may influence IRD width. The number of severe diastasis cases was small, as expected, and speculation on its effects is not possible based on this study. The response rate was also rather low. Study III was small. In Study IV, there were few hernias (which were small) and no recommendations can be made for midline hernia repair. Study IV was a case series of an experienced plastic surgeon, and the results may not be representative of other circumstances. Although RAND-36 is a robust HRQoL tool, BodyQ may have offered more sensitivity and resolution in this patient group.

In plastic surgery trials, it is difficult to distinguish the effect between aesthetic and functional improvement. That was also the case in the studies presented in this thesis; the change in abdominal contour after surgery may disguise the functional results. On the other hand, from clinical experience it appears that the effect of the aesthetic dimension is not greater than that of reduction mammaplasty, for example. The change in an individual's everyday life after RD repair is in many cases notable regardless of satisfaction on the aesthetic result.

6.7 FUTURE PROSPECTS

Although women have always had children, surprisingly little is known of the effects of pregnancy on the abdominal wall. Research on RD is only in its infancy. It is unclear what is normal and what is a diagnostic. It also remains unclear if normative values should be re-evaluated if a considerable proportion of mothers are abnormal according to current definition without any symptoms in future studies.

Patient identification for surgery requires evidence-based data, especially in public health care. Based on this thesis, it appears that mild (2-3 cm) and moderate diastasis (3-5 cm) do not differ in RD-related back pain or core instability at a population level. Three centimeters may not be a relevant lower limit for surgery, although there are some exceptions with substantial lateral laxity where surgery may be beneficial even with narrower IRD. Scaling the amount of lateral laxity and abdominal wall bulging pre-operatively is challenging not only in the context of research but also in clinical setup. More data are needed on Nahas B-type diastasis and associated management.

Based on this thesis, severe (>5 cm) symptomatic diastasis seems to benefit from surgery. It is worth noting that especially the long-term results of

surgery are lacking, and final conclusions are possible only once these are available. Numerous operative approaches have been developed in the past decade. A comparison of different laparoendoscopic techniques and laparoendoscopic techniques and abdominoplasty warrants RCTs.

In the future it would be interesting to know more on the effects of severe diastasis. It is unknown how many of those with severe diastasis are symptomatic. The compensatory mechanisms that make the core stable with a wide linea alba are also unknown. More information on physiotherapy in general is needed. Linea alba does not heal particularly efficiently and the best approach to post-operative rehabilitation is unclear. When and to what degree of intensity one can start exercising after surgery is unknown. According to clinical experience, women with normal weight, high physical functional demands, and wide post-pregnancy diastasis suffer from RD the most. This patient group seems to be interested in getting back to unrestricted exercise early.

Study IV is too small to challenge the current consensus of the need of mesh with combined RD and hernia. Conclusions can be made in the future if long-term results of RCTs are available.

7 CONCLUSIONS

RD in not an aesthetic problem or a consequence of insufficient physiotherapy. The main conclusions of this thesis are

1) Mild RD (<3 cm) seems to be common. Severe diastasis (>5 cm) is rare. Mild and normal vs moderate diastasis do not seem to differ regarding symptoms of back pain or core instability at a population level.
2) Those with more lumbar back pain or core instability after pregnancy seem to have wider IRD.
3) The operative treatment of symptomatic, severe diastasis not responsive to conservative treatment is beneficial. The functional results were good and the complication rate was low with two different operative modifications (PSUM and HELP). The incidence of hernia or RD recurrence seems to be low in short-term follow up. It is possible to operate a RD-related hernia without a mesh in a normal-weight patient group when the entire midline is corrected.
4) The effect of surgery on HRQoL and RD-related symptoms is significant when RD and lateral laxity are addressed in a normal-weight patient group with severe diastasis or prominent protrusion of the abdominal wall.

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